

TRANSACTIONS

American Society for Steel Treating

VOL. XI

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NO. 2

THE WINTER SECTIONAL MEETING

THAT the Winter Sectional Meeting of the Society was a success is fully attested by the enthusiasm shown by those who were in attendance. This meeting was the ninth sectional meeting of the Society and was well arranged by the members of the Washington-Baltimore chapter. The meetings were held in the spacious Hotel Mayflower on Thursday and Friday, January 20 and 21, 1927. However, quite a large number of members and the Board of Directors gathered on Wednesday, January 19, for the purpose of holding meetings for the discussion of Society matters. Two committees, in addition to the Board of Directors, held executive sessions. These were the Publication Committee and the Recommended Practice Committee. Following these meetings the "Early Birds" dinner was held at the Cosmos Club and was followed by a theater party. A large number of the Washington-Baltimore chapter members attended these last two functions.

A report of the Board of Directors meeting will be published in the March issue of *TRANSACTIONS*.

The complete program of the meetings and technical papers which were presented at this sectional meeting was published in the January issue of *TRANSACTIONS*, page 12. This program was carried through exactly as scheduled and in a manner which reflects much credit on the able and efficient committees on arrangements of the Washington-Baltimore chapter.

At 9:00 a. m., Thursday morning, regular registration of members and guests was begun, and at 10:00 o'clock the first technical session was called to order. President Harper extended greetings to the assembled members and guests, then introduced J. G. Yaden, president of the Federation of Citizens' Associations of Washington, who extended an official welcome to the nation's capital city. Following these preliminaries the technical

program was started by the chairman, Edgar C. Bain, metallurgist, Union Carbide and Carbon Research Laboratories, Long Island City.

The three papers scheduled for this session were presented in the following order.

Review of the Metallurgical Activities of the Washington-Baltimore District—Emil Gathmann, president, Gathmann Engineering Company, Baltimore.

Wear Resistance of Cutting Edges of Blanking Die Parts and Shear Blades—W. J. Merten, metallurgical engineer, Westinghouse Electric and Manufacturing Co., Pittsburgh.

Iron-Carbon-Vanadium Alloy for Brinell Balls—G. W. Quick, assistant metallurgist, and L. Jordan, chemist, Bureau of Standards, Washington.

Thursday afternoon was devoted to inspection trips, one group visiting the Baltimore Copper Rolling and Smelting Company at Baltimore, and another group visiting the United States Naval Gun Factory, Washington Navy Yard. These inspection trips were especially well attended.

At 7:00 p. m., the usual banquet was held in the Chinese Room of the Mayflower Hotel and was attended by more than 100 members and guests.

President Harper after a short address of welcome, introduced the toastmaster, W. M. Corse, who, in a very interesting manner, introduced each of the speakers of the evening.

The members were accorded an unusual treat in hearing talks by two men holding high posts in the army and navy ordnance departments. Admiral C. C. Bloch, chief of the Bureau of Ordnance, United States Navy, traced the development of war ships and naval armament through the various periods of its history, stressing the importance of the influence of the navy upon the development of the use of steels.

Colonel W. H. Tschappat, chief of the technical staff of the Army Ordnance Department, likewise traced the development of the progress made in land military equipment in which he described the progress made in the various branches of army ordnance.

The third speaker, W. P. McCracken, Jr., assistant secretary of commerce, gave a very interesting talk on the development of airplane transportation in which he pointed out the advance which has been made in aeronautics, especially since the war period.

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The second technical session was called to order Friday morning at 10:00 a. m. by the chairman, Dr. H. W. Gillett, chief of the division of metallurgy, U. S. Bureau of Standards. Two papers were scheduled for this session, namely:

Centrifugal Casting of Steel—Leon Cammen, associate editor of "Mechanical Engineering" and consulting engineer, New York City.

Fundamental Research on Nonmetallic Inclusions in Steel—Dr. C. H. Herty, physical chemist, Bureau of Mines Experiment Station, Pittsburgh.

These two papers were well presented by their respective authors and presented some of the latest developments in the steel industry, the first paper dealing with the centrifugal casting of steel, and the second paper dealing with the structural properties of steel. Many members and guests entered into a discussion of these two papers and the discussions will be published in *TRANSACTIONS* together with the papers.

Friday afternoon was devoted to two inspection trips, one to the Crown Cork and Seal Company at Baltimore, and the second to the United States Bureau of Standards. The second inspection trip was by far the best attended and many members and guests availed themselves of the opportunity of seeing at first hand the work which is being done at the Bureau.

The third and final technical session was called to order by the chairman, Dr. G. K. Burgess, director of the United States Bureau of Standards, at 8.00 p. m. This session was devoted to a discussion of the subject of normal and abnormal steels. The two papers presented are as follows:

Progress in the Study of Normal and Abnormal Steel—S. Epstein, associate physicist, and H. S. Rawdon, physicist, Bureau of Standards, Washington.

Normality of Steel—J. D. Gat, metallurgical engineer, research department, Central Alloy Steel Co., Canton, O.

A lively and interesting discussion followed the presentation of the two papers which brought out many of the points of difficulty which have been encountered in the study of the so-called normal and abnormal carburizing steels.

Both the written and oral discussion will appear in *TRANSACTIONS* when these papers are published.

There were seven papers in all which were presented during this two-day meeting. These papers had been preprinted and distributed to those members who signified their desire to have

them. This is the first time that the papers presented before a sectional meeting were available in preprint form.

In commenting upon the Winter Sectional Meeting held January 20-21, *Iron Trade Review*, in its January 27, issue, said in part:

"Convening for the first time in the Capital City, the American Society for Steel Treating held its winter sectional meeting at the Mayflower, Washington, January 20-21. Selection of this city as a meeting place was most appropriate for in the Washington-Baltimore district is situated an unusual scope of metallurgical activity, both commercial and scientific. The Bureau of Standards, for example, is engaged in many lines of research most intimately related to the production, fabrication and heat treatment of metals.

"The meeting, which lasted two days, followed the customary plan of combining technical sessions with inspection trips. Sessions were conducted on Thursday and Friday mornings and Friday evening. A dinner was served on Thursday evening. Among plant visitations of unusual interest were those to the Washington navy yard on Thursday afternoon and the Bureau of Standards on Friday afternoon.

"Attendance at the meeting was somewhat below average, due to Washington's distance from some of the more important iron and steel centers, nevertheless, the quality of technical contributions was up to the usual high standard of previous sectional meetings. Notable among the papers were two dealing with normal and abnormal steels, one on nonmetallic inclusions in steels and another on the centrifugal casting of steel. The topics of centrifugal casting and normality of steel were subjected to considerable discussion."

In its January 27, issue, *Iron Age* says in part:

"Another interesting and successful sectional meeting of the American Society for Steel Treating was held in Washington, January 19, 20 and 21. According to the well-laid plans of the Washington-Baltimore chapter, the annual winter sectional meeting at the Hotel Mayflower was featured by several valuable contributions to technical questions. Though the attendance of about 150 was not so large as at some of these other regional conventions, the enthusiasm and results were notably satisfactory.

"The first complete presentation of a new process for casting steel centrifugally was a feature of the technical program. It developed marked interest. A paper on the study of inclusions in steel was a valuable contribution to a vital steel-making problem. This is the first occasion when papers on such subjects formed part of the program of a sectional meeting.

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and 'abnormal' steel was also a feature of last week's gathering. The contribution from members of the staff of the United States Bureau of Standards clarified this question to a marked degree. Some problems connected with hardness also received attention."

A. I. M. M. E. MEETING

THROUGH the courtesy of the Board of Directors of the A. I. M. M. E. transmitted to the A. S. S. T. through Secretary H. Foster Bain, an invitation has been received and accepted for the members of the American Society for Steel Treating to participate as guests with the A. I. M. M. E. and the Institute of Metals at their annual meeting held in the Engineering Societies Building, 29 West 39th Street, New York, February 14 to 17, 1927.

A special letter notice of this meeting was mailed to members of the society due to the fact that the February TRANSACTIONS would not arrive in time to advise members of this invitation.

The schedule of events which will probably be of most interest to members of the A. S. S. T. is as follows.

Tuesday, February 15

2:00 P. M.—Institute of Metals Zinc Session.
2:00 to 4:00 P. M.—Iron and Steel. Papers by Grossmann; Lindemuth; Langenberg; Bain and Griffiths; Krivobok.
4:00 P. M.—Henry M. Howe Memorial Lecture. Alloy Steels by Bradley Stoughton.
6:30 P. M.—Institute of Metals Dinner, Fraternity Club.

Wednesday, February 16

9:30 A. M.—Iron and Steel Round Table; Carbon in Pig Iron.
9:30 A. M.—Institute of Metals Copper Session.
2:00 to 4:00 P. M.—Institute of Metals Aluminum Session.
4:00 P. M.—Annual Lecture. The Growth of Metallic Crystals by Prof. Cecil H. Desch, Sheffield University.

Thursday, February 17

9:30 A. M.—Institute of Metals General Session.
2:00 to 4:00 P. M.—Institute of Metals Nonferrous Metallurgy.

Your appreciation of this invitation may be shown by attending as many sessions as possible.

BELATED RECOGNITION

HONORABLE ANTHONY J. GRIFFIN, member from New York and the House of Representatives, introduced on December 7, 1926, a bill that is indeed worthy of immediate attention and one that should be passed by both Houses of Congress.

The bill provides "that the President of the United States should be authorized to present in the name of Congress, a medal

of honor and written testimonial to scientific workers of the Federal Government whose labors have contributed to the advancement of scientific knowledge or applied its truths in a practical way for the welfare of the human race."

The bill further provides "that not more than five scientific workers shall receive the medal in any one year and that the persons so honored shall receive the sum of \$100.00 on the presentation of the medal and testimonial, and thereafter, annually for life, a sum of money the amount of which shall be fixed by the commission making the award; said sum to be not less than \$100.00 and not more than \$500.00 per annum, which said sum shall be exclusive of salary or pension."

There are many outstanding achievements of the men connected with the scientific departments of our government and these have passed on from the earliest time to the present entirely unnoticed and unrecognized.

Our thanks are due to Congressman Griffin in presenting this bill to the attention of Congress and it is sincerely hoped that this belated recognition may be speedily attained.

ADVANCES IN FERROUS METALLURGY

NO doubt many readers of TRANSACTIONS have noted with interest the exceptionally fine Annual Review Number of *Iron Age*, January 6, 1927. In this issue there appear several general reviews covering the advances for the past year in various fields of industry. These reviews have been written by men well qualified by their experience to observe those things which are of outstanding importance.

It is interesting and important to note that of the 50 references quoted under the 5½-page article entitled "Ferrous Metallurgy Advances", the author, Prof. H. M. Boylston, names and discusses 15 articles which have previously been published in the TRANSACTIONS of the American Society for Steel Treating.

Is it not with a feeling of satisfaction that members of the American Society for Steel Treating realize that their Society is made up of men who are contributors in such a large degree to the recent advances in the art and science pertaining to the manufacture and heat treatment of steel and allied industries?

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INVESTIGATION OF BOLT STEELS

BY V. T. MALCOLM AND JOHN JUPPENLATZ

Abstract

Due to the advent of higher pressures and temperatures in the power plants and oil refineries, materials of greater strength and rigidity are demanded in order to be in trend with the rapid strides of advancement in these industries today. The authors of this paper have set forth some of their findings of investigations made upon bolts and bolt materials obtained after several years of study. The investigations cover tests upon failures under actual working conditions, remedies and recommendations based upon the results of tests.

They point out that not only heat treatment, physical tests and chemical analysis of raw material are important, but the method of manufacture, rigid inspection and safe-guards are especially necessary for highly or heavily stressed parts. To meet these demands, a heat treated alloy steel bolt has been recommended to supplement the carbon steel bolt and tests upon both of these materials are covered in detail. The art of testing and modern testing methods are discussed, more particularly, the methods of high temperature short and long time testing. The importance of these tests is emphasized. Test data and charts pertaining to bolt material are given.

The authors, in concluding, are of the opinion that all of the advantages claimed for case-hardened nuts may be had without the bad effects by the use of a medium carbon heat treated steel nut. Several photomicrographs and photomacrographs of failed and satisfactory materials are presented together with a comprehensive bibliography.

FOREWORD

GREATERT economy and security in central station and oil refinery development require the designing engineer to have an accurate knowledge of the properties of metals under stress at high temperature. In December 1922, a contribution to the "Power Session" at the American Society of Mechanical Engineers con-

A paper presented before the eighth annual convention of the Society, held in Chicago, September 20 to 24, 1926. Of the authors, V. T. Malcolm is metallurgical engineer, and John Juppenlatz is metallurgist, The Chapman Valve Manufacturing Company, Indian Orchard, Mass.

vention was presented by Orrok and Morrison, (1)* which created a new interest in the development of high pressure central stations, as the paper set forth the importance of having reliable information available.

Great interest in this subject was stimulated by the discussion and one of the authors of this contribution entered into the discussion and presented some new and heretofore unpublished results of tests of metals at elevated temperatures as made in our laboratories; and from the paper presented by Orrok and Morrison and the discussion that followed, it was shown that certain materials were fully capable of operating successfully at temperatures and pressures proposed. (2)

Later a sectional committee on standardization of steel pipe flanges and fittings was organized under the procedure of the American Engineering Standards Committee, under the sponsorship of the Heating and Piping Contractors National Association, The Manufacturers' Standardization Society of the Valve and Fitting Industry and the American Society of Mechanical Engineers.

At an informal meeting in May 1923, this committee organized and out of this meeting there was evolved a definite program of cooperative standardization and research for flanges and flanged fittings for high pressures and temperature.

The American Society for Testing Materials joined the work of standardization by organizing Sub-Committee 22 on pipe flanges and fittings of committee A-1 on steel, in order to develop material specifications for high temperature service.

As a result of the activity of these various committees, a symposium on the effect of temperature on the properties of metals, (3) was held in Cleveland, May 1924, at a joint meeting of the two societies and from the result of this symposium and discussion that followed, the joint research committee on the effect of temperature on properties of metals was organized.

Dimensional standards have been developed by the Sectional Committee and Material Standards by the American Society for Testing Materials committee for high temperature work, and as this paper refers to bolt materials for high pressure, high temperature work, the authors suggest the inspection of American Society

*The figures appearing within parentheses refer to the references appended to this paper.

for Testing Materials standard A 96-25 for alloy steel bolt material for high temperature service.

BOLT MATERIALS AND BOLTS

During the informal meeting of Sectional Committee in May 1923, (4) it was stressed that considerable difficulty was experienced with bolt material for power plant work, and due to these difficulties the public service companies were losing thousands of dollars and we saw the urgent need of a systematic study with the view of having a standard specification for bolts and nuts.

The authors had at that time devoted quite some study to the investigation of bolt materials for high pressure and high temperature installations and in this paper are presenting some of their findings of this study. Years of investigation were necessary in order to gain the end, for it must be remembered that the material must conform to rigid specifications and be guaranteed for the service intended.

Sabin Crocker (5) states that in placing an order for material to be used in high temperature service, it is necessary to specify at what temperature it will operate and require the manufacturer to guarantee that it will prove satisfactory for the purpose intended. This is not only a necessary precaution for self-protection on the purchaser's part but it gives to manufacturers a fair chance of either furnishing material that he knows is right, or else to decline orders.

To stand back of such guarantees and to assume the risk implied, it is essential that manufacturers be in close touch with the selection of proper material and be familiar with every step in the process of manufacture; and that theory and practice be so co-ordinated and manufacturing methods developed to a high state of efficiency, that quality is the paramount feature. That steel is steel seems to be the general idea of many people, but the mere fulfilling of a given set of specifications does not present itself as the vital feature unless it is shown that the specifications themselves are correct.

The framing of specifications depends upon antecedent knowledge of the behavior of steel bolts under conditions to which they will be subjected in service, and in view of the acknowledged importance of steel bolt material for high temperature service, it becomes a necessity for those interested in this class of work to

investigate their materials so that a thorough knowledge of the physical characteristics will be available and their limitations known, because a failure in service is a serious matter.

If we study the bolt material specifications we find a lot about heat treatment, tests and analysis, but nothing is stated about raw material or the manufacturing method except to specify the process by which the steel is to be made, and that the steel must be free from injurious defects. From this we may infer that as long as the bolts meet the clauses specified, the quality of the material and methods of manufacture are not questioned, and any failure in service must be from some other source than material. This inference is incorrect for while certain materials for bolts meet the specifications, manufacturing methods may cause a lot of trouble to the ultimate consumer.

With such conditions in mind it is of the utmost importance to place rigid inspection and safeguards other than specifications on the material to insure it being correct for the purpose specified. This statement, of course, only refers to material for use in high class work, as we would not expect to take such great care in the inspection of material in unstressed parts.

In the past years the quality or rather the lack of quality in bolts was judged by their performance in service, but this was rather a costly means and is now being discarded and replaced with the art of testing which has developed greatly and in keeping with the science of metallurgy.

As ordinary soft carbon steel bolts filled the requirements several years ago, so did the ordinary static tensile test fulfill all the necessary requirements to judge and accept steel bolts, but today, engineers are demanding material in their bolts that will "stay put" and in order to develop such materials it was necessary to delve deeply into research.

In carrying out investigations on steel at high temperatures a study must be made of the properties of the metal, such as its resistance to shock, its endurance or fatigue limit, its torsional elastic limit, its hardness and machinability, its toughness and wearing qualities, its resistance to corrosion, its thermal expansion, and finally its ability to withstand constant pressures at elevated temperatures over periods of long duration without distortion or failure.

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TROUBLES ENCOUNTERED

Periodically trouble is encountered with bolts in power plants and refinery equipment which may cause considerable expense and worry due to the closing down of important units and thus seriously

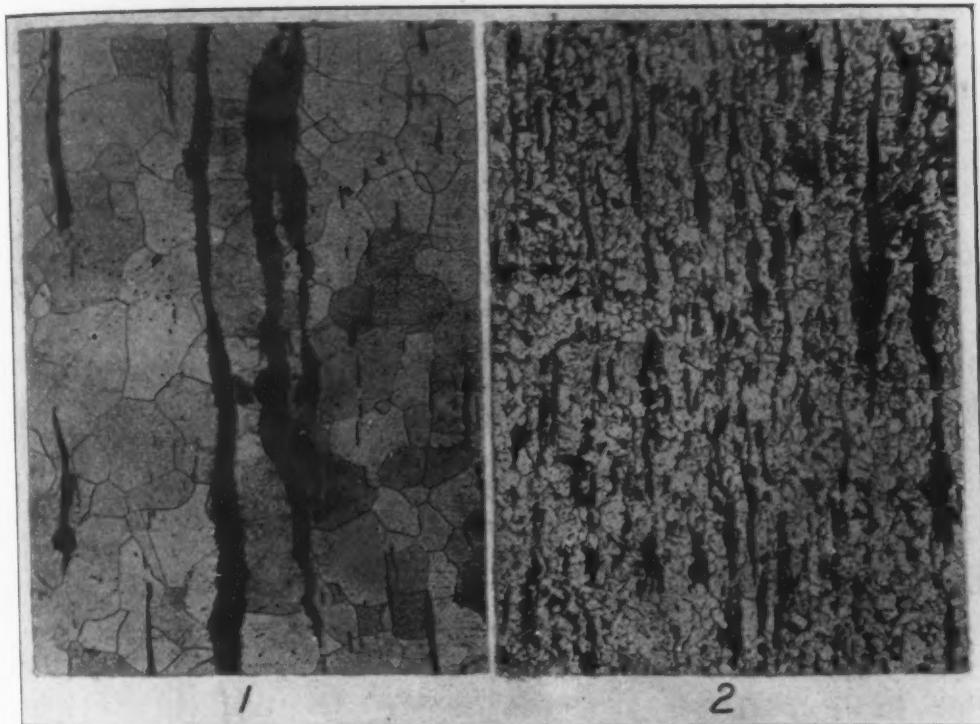


Fig. 1—Photomicrograph of Outer Section of Low Carbon Steel Bolt Showing Slag Streaks and Nearly Pure Ferrite. Etched with Nital. 100x. Fig. 2—Photomicrograph of Inner Section of Low Carbon Steel Bolt Same as Fig. 1, Showing Dark Bands of Pearlite and Gray Elongated Particles of Manganese Sulphide. Etched with Nital. 100x.

affecting production. Too little attention has been given to this important though somewhat obscure detail of plant operation, and it is only of late that any real attention or investigation has been undertaken.

Steam plants and refineries operating in excess of 250 pounds (4) pressure have had considerable trouble with bolt material and reports indicate the material to be brittle after several months of service so that the heads could be snapped off with a hammer. In some cases our attention has been called to bolts that were broken while the pipe lines were being assembled.

Bolts sent to our laboratory for examination showed in nearly every case that the material was carbon steel, wrought iron or screw stock containing high sulphur and phosphorus. At the same time

it was noted that nearly all the bolts had forged heads, and in Figs. 1-2-3-4-5 it will readily be noted that the flow lines due to upsetting, break off under the shoulder and set up additional strains so great that bolts inspected in a number of cases were found to be cracked completely across the section.

Engineers connected with power plants are now making most careful examinations of specifications and the character of bolt materials entering into their work, (6). As bolts are important

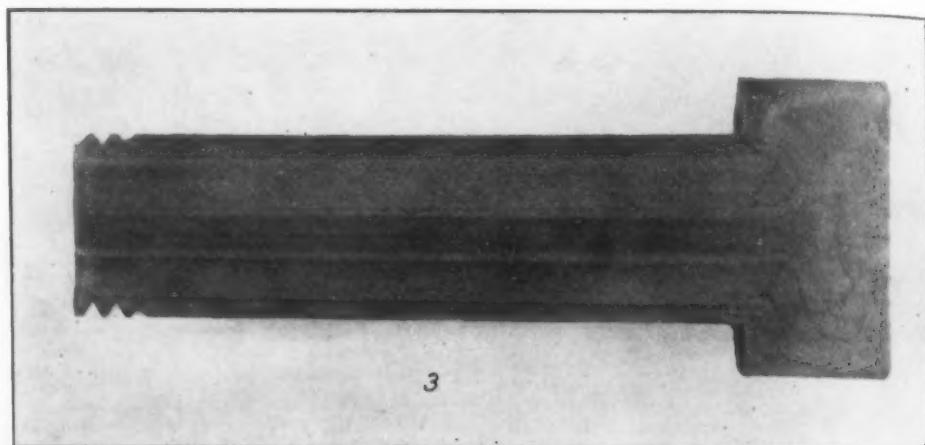


Fig. 3—Photomacrograph of Bolt from which Photomicrographs of Figs. 1 and 2 were Obtained. Etched with 10 per cent Ammonium Persulphate. $\frac{1}{2}$ Actual Size.

links in this work it is the aim to produce a bolt that will completely serve the purpose, i. e. to provide a quality product that is justified by the use for which it is intended and to produce these bolts with the least possible expense commensurate with quality.

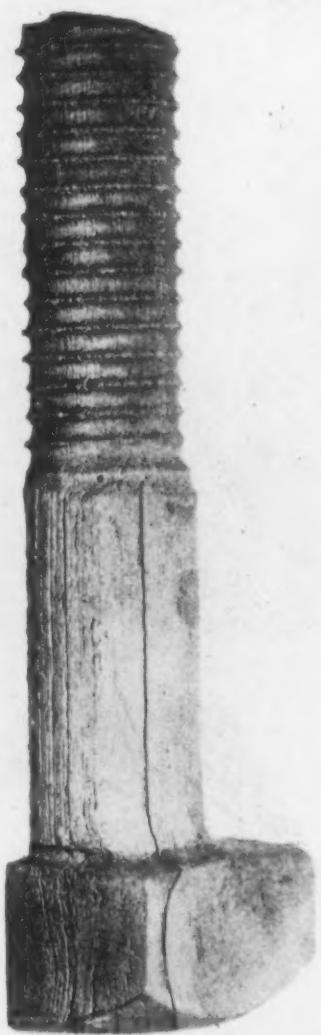
When the standardization of bolt materials was undertaken in 1923, the tendency was to use carbon steel bolts in the construction of plant piping, believing that by the use of a carbon steel bolt, the ductility would be increased and therefore the life of the bolt increased. It was, however, demonstrated that the ductility of steel in tension certainly was or is not the criterion of the endurance or impact value of the steel.

For instance, in the case of soft carbon steel bolts which have shown good ductility when tested in tension, we find that they have a low resistance when subjected to the impact test and this low resistance to impact certainly shows low cohesive properties of the metal itself and therefore a low fatigue value.

One of the most common expressions we hear in accounting

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Fig. 4—Forged Carbon Steel Bolt. Hot Etched with 1:1 HCl. Note the Crack under the Head and Cracks and Seams Extending Throughout the Bolt. Fig. 5—Photograph of Section of Wrought Iron Bolt Found in High Pressure High Temperature Installation.

(7) for failure of bolts is that failure was caused by "crystallization" of the steel. This is an erroneous idea, and undoubtedly originated from the appearance of the fracture and should be known as a "fatigue failure" or a progressive failure produced from stresses beyond the elastic limit, and in which part of the fracture appears more or less smooth and the remainder granular or

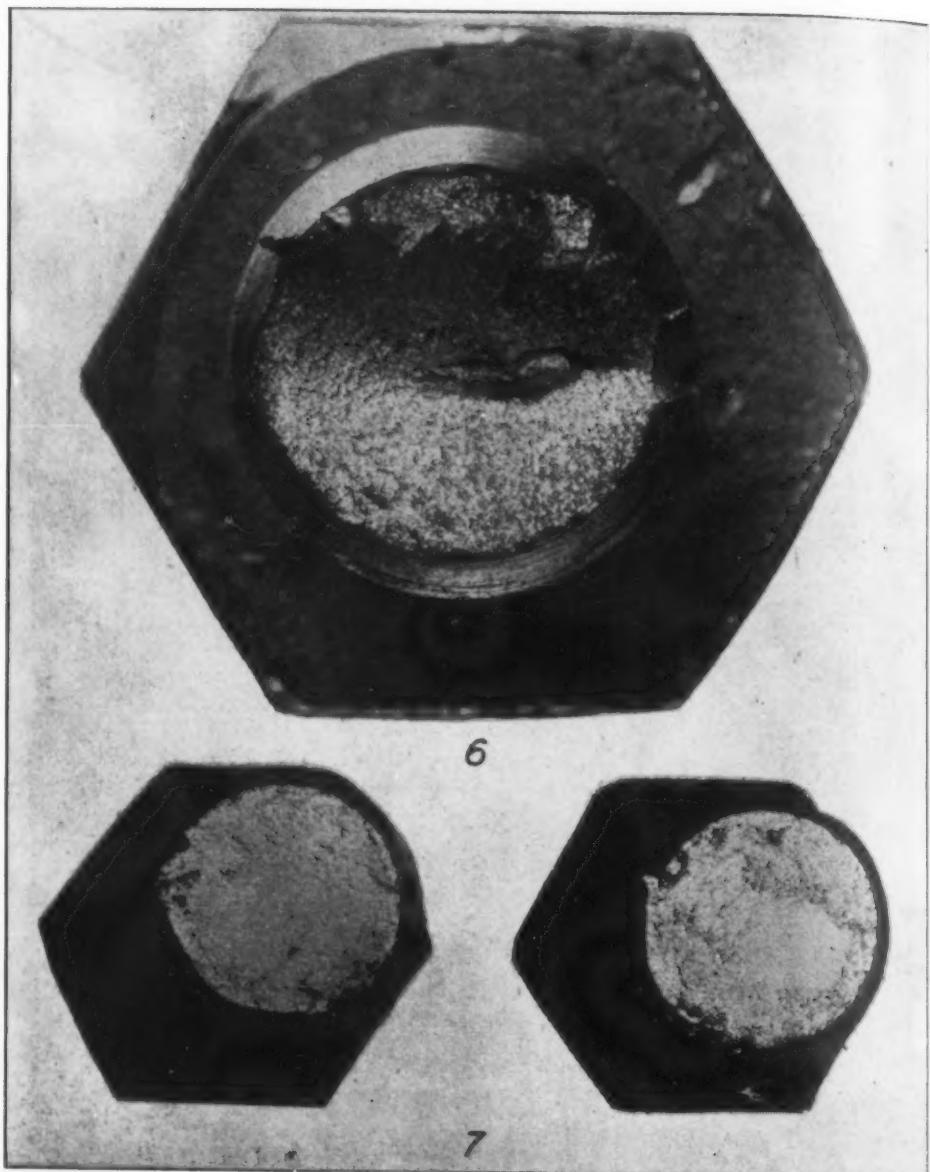


Fig. 6—Photograph Showing Typical Fatigue Failure in a Bolt, and Shows how Fatigue Cracks Gradually Spread. The Light Colored Areas Show Where the Cross Section Finally Failed Statical. Fig. 7—Showing a Number of Bolts that Failed from Fatigue Caused by Expansion Stresses Due to Changes of Temperature.

crystalline. Every fatigue break or failure in bolt steel shows a crystalline fracture just as every cross section of steel that has been "nickled" and broken shows it, but, the characteristics of this fracture have absolutely no bearing on the original condition of the metal. See Fig. 6.

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are large, shiny and bright, and cause the erroneous term "crys-tal-lization" to be used, but as steel is originally a crystalline mass it is obvious that it cannot "crystallize."

Extensive series of fatigue tests on a variety of steels, from a standpoint of composition, heat treatment, etc., have been made, and from the results of these tests it has been found that the maximum fatigue limit follows directly or is directly proportional to the tensile strength of the steel. Any heat treatment that has a tendency to increase the tensile strength also increases the resistance of the steel to fatigue. From this it may be noted that properly heat treated alloy steel has a strong resistance to fatigue even though the ductility is lowered thereby. It is therefore unfortunate that an impression still exists in such instances that good resistance to fatigue may be assured in all cases by merely obtaining high ductility in tension.

We recognized many years ago that the only safe bolt material for high pressure elevated temperature service was a properly heat treated alloy steel made into studs, with nuts on each end. The higher elastic limit obtained with its use was far greater than that found in carbon steel bolts used several years ago and this higher elastic limit has tended to give a higher factor of safety even after the bolt has been subjected to expansion stresses due to heating and alternating stresses due to vibration. These stresses when combined with the stress from steam pressure are well within the elastic range of the steel. Results obtained with alloy steel bolts after years of service have proved satisfactory.

From the result of our investigations we found that stresses in bolts are complicated and extremely difficult to calculate either analytically or graphically, and from the results of these investigations it is believed that there are four principal types of stress set up in bolts when used in high pressure, elevated temperature work, which stresses are listed as follows:

1. Torsional stresses, due to setting up
2. Mechanical stresses, due to pressure
3. Temperature stresses, due to expansion and contraction (caused by changes of temperature in steam or vapor lines) between the bolts and the flanges
4. Alternating or repeated reversals of stress caused by vibration.

It is probable that temperature stresses are the most severe, when it is realized that nuts on studs are individually "drawn up" when flange joints are cold, and in most cases, they are not tightened equally around the flange.

Steam or hot gases are admitted to the pipe line and all parts are heated up to quite a temperature causing stretching or expansion of the stud bolts. When the line is shut off all parts are cooled and if the stud bolts return to their original length as when first "drawn up" the joint will be tight, if they have taken a "permanent set" the bolt is strained and, of course, will not return to its original length and the joint will leak. This is a common occurrence with low strength bolts, and when a joint leaks, they are again "drawn up" and this operation being repeated till finally the strains set up are so great that the bolt fails, the fracture being "cristalline."

Torsional strains are introduced in cases of assembly either in the works or in the erection at the plant and are sometimes so severe as to introduce permanent set before the steam line has been placed in service. It must be realized that when a number of bolts are used as in a flange joint, the load carried by each bolt depends on its relative tightness, the tighter the bolt the greater the load. Bolts when drawn up tightly, have an initial stress placed in them due to pulling up before the pressure is applied and this stress may vary between 16,000 and 30,000 pounds per square inch.

The necessity of the cycle of operation from normal temperature to operating temperature is a factor more than any other which limits the "life" of bolts in power plant and refinery operation. Certain stresses not readily calculated due to nonuniformity of temperature distribution cause more failures than any other single case we know of. Fig. 7.

When thermal expansion stresses exceed the elastic limit of the bolts they produce practically deformed areas which are "set" for the highest operating temperature of the cycle and very likely cause failure when the temperature returns to normal after repeated cycles.

Therefore one of the greatest problems that confront the manufacturer and consumer of bolts is the knowledge or lack of knowledge of the ultimate endurance limit of bolts under action of

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According to Oberhuber and Aberle (8) there is no practical way of telling what load is placed on the end of a wrench, and it is a matter of conjecture as to the amount of stress upon the bolt. It was found in their tests that 88 per cent of the work was dis-

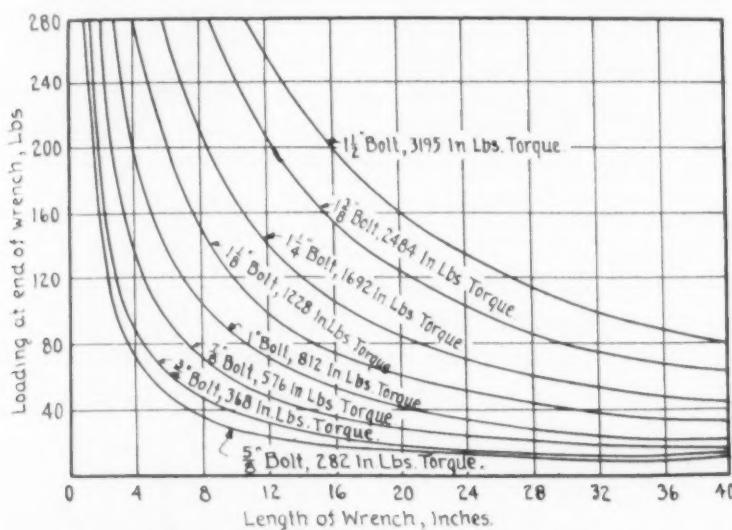


Fig. 8—Graphs Showing Lines of Constant Torque for Various Sizes of Bolts and Lengths of Wrenches.

sipated in friction and the remaining 12 per cent being used in stressing the bolt. They also found that the fiber stress in the bolts tested increased directly as the load at the end of the wrench. Fig. (8) was prepared from some of these tests, and shows lines of constant torque for various sizes of bolts stressed up to 10,000 pounds per square inch. The load may be found if the length of wrench is known and vice versa.

These assumptions and tests have been confirmed by recent service tests in one large power station where an attempt was made to determine the stress due to "setting up" and to expansion caused by temperature. (9)

In this investigation the bolts were carefully measured, and inserted into the flanges, and after drawing up the joint in an ordinary manner the bolts were again measured. The boiler was then placed in service, the temperature of steam being near 750 degrees Fahr., and while the steam line was in service the bolts were again measured. The bolts were removed as soon as the boiler was

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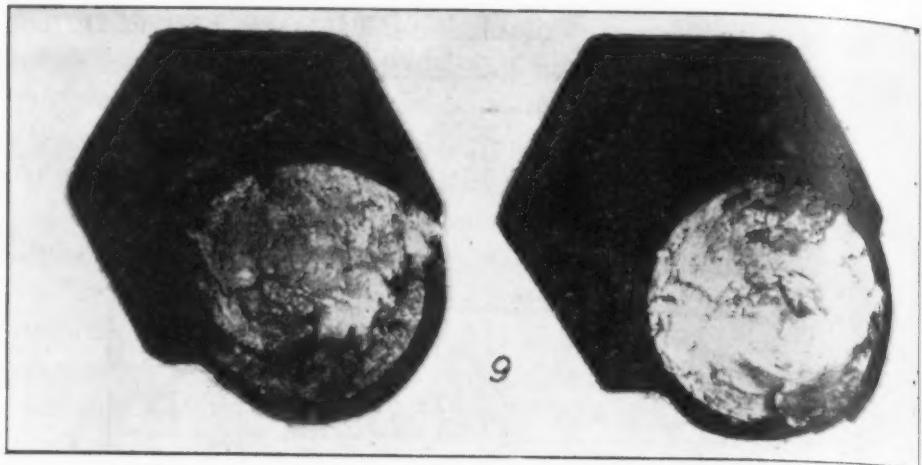


Fig. 9—Photographs Showing Bolts which Failed due to "Pulling Up" Stresses Shortly After Steam Line had been Placed in Service.

cold and check measurements of the original length were made. This cycle was repeated several times and the report shows a total stress of 110,000 pounds per square inch on $\frac{5}{8}$ inch diameter bolts and a permanent set of 0.0004 inch after the first cycle. It was

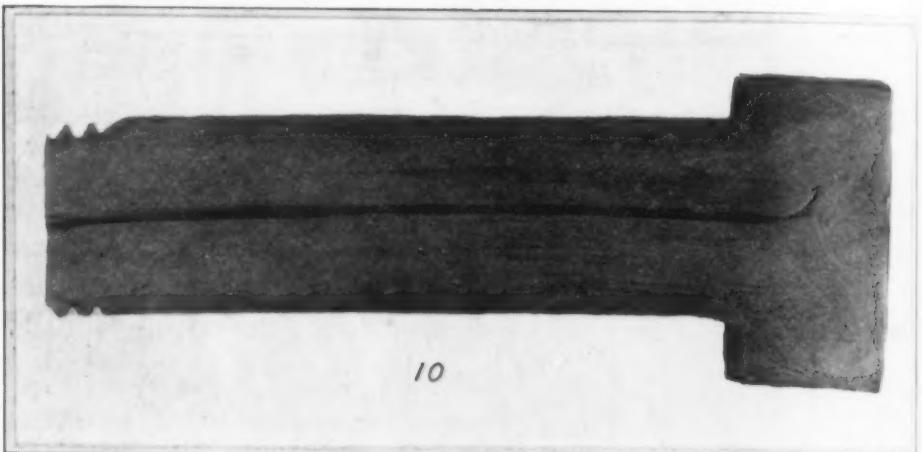


Fig. 10—Photograph of a Carbon Steel Bolt that Failed while pipe Line was being Assembled. Note Pipe in Center of Bolt. The Bend Shown in the Picture was Caused by the "Setting Up Pull." Etched with 5 per cent Picric Acid. $\frac{2}{3}$ Actual Size.

also reported that the stress set up in bolts due to "pulling up" was 52,000 pounds per square inch. This is apparently an extreme case but tends to show why bolt material fails.

Certain other tests (10) show that if a four-foot lever is used on a wrench in tightening $1\frac{1}{4}$ inch bolts with 50 pounds static pull a stress of 5700 pounds per square inch will be set up. Using a

5-foot lever per square inch hammer, on a tension of 14,000 second case tension will

It must be continued after these bolts will

Every strain, or deformation which strains the limit of the corresponding

When material is strained and considered a permanent left over after the permanent

Troendly mechanics of the proposed structure that strain of hardened formed of him in strength in the opposing

When we the small amount directly to the constitutes the retaining. If the previous paragraph has taken place effect remains in the bolts beyond

5-foot lever arm 150 pounds static pull, a stress of 25,800 pounds per square inch will be set up. If a blow is struck with a 3-pound hammer, on the bolt as in the first case with 50-pound pull, a tension of 14,000 pounds per square inch will be set up, and if in the second case with 150-pound pull, 34,100 pounds per square inch tension will be set up.

It must therefore be recognized that if "pulling up" is continued after several cycles of operation it will not be long before these bolts will be in an overstrained condition. Figs. 9 and 10.

Every stress, no matter how small produces a corresponding strain, or deformation in the shape of the body acted upon; and which strains increase with the stress. The stress and corresponding strain are directly proportional up to a certain point which is the limit of proportionality, below which by removing the stress the corresponding strain will disappear and the material is said to be elastic.

When metal is deformed beyond this point it is said to be overstrained and according to Wood (11) overstrain might be considered a part of the total elastic deformation of a piece of metal, left over after the external load has been removed, and that added to the permanent deformation due to plastic action, will give the total permanent deformation.

Troendly and Pickwell, (12) submitted a new theory on the mechanics of overstrain, which might be called the plastic transfer of the proportional elastic range. They conclude from their evidence that strengthening due to cold work is not through the formation of hard amorphous material which renders the section deformed of higher elementary unit strength, but that the increase in strength in any direction is at the expense of the strength in the opposing direction.

When we consider the grave importance of this condition and the small amount of data available we are surprised, for it leads directly to the problem at hand, i. e. the cause of failure and what constitutes the limiting stress that the bolts are capable of sustaining. If the stud bolt has been overstrained as noted from the previous paragraphs, we may say that a permanent change in size has taken place, which resulted from the force applied and the effect remaining after this force has been released. Straining of bolts beyond the elastic limit certainly introduces internal strains

which measure the resilience of the steel bolts when the internal strains are released.

A strain which affects the full cross section of the bolt nearly uniformly presents certain information so that the elastic recovery may be observed and the effects of strain determined. The effect of an overload may cause increased rigidity for loads higher than the original one and the effect of this overload on the range of resilience of the metal in the plus and minus directions is noticeable and permanent set is introduced in the steel when stresses are reversed, and a general change in the metal takes place with decreased ductility.

The cumulative effect of this repeated alternation of stress is well known and exemplified by rupture of bolts, without any display of an appreciable amount of ductility regardless of the original ability of the metal to show good ductility in the tension test. This assumption agrees very closely with that of Troendly and Pickwell that elastic bodies have an available range of elastic deformation which is probably terminated by an abrupt breaking strength.

It is a known fact that bolts will endure prolonged stress without fracture even when such stress more than equals several times the sum of two stresses which have affected rupture by repeated alternate loads of tension and compression, which stress may be set up by expansion and contraction due to temperature changes.

However, it is necessary in this connection to take into consideration not only the stresses which result from external loading, but also the state of internal strains which have developed in the steel. This second factor is one that has been overlooked generally in engineering structures and little consideration has been given to the influence of internal strains in the steel. These strains in our opinion are just as tangible as those which result from external loads and it is believed that they account for failures which have not been adequately explained for reason of the magnitude of external strains. While it is somewhat difficult to obtain a mental picture of bolts under strain yet the effect of strains is apparent when a section of a bolt breaks off without being touched or with a slight blow of a hammer; it is evident that the damage was caused by some internal force.

As steel metal under crystals are. This change "slip" or another alone,ized, the m quantity of action. Mo to such an e line conditio ments are amorphous crystals begin flaw started results with

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MECHANISM OF FAILURE

As steel used in bolts is an aggregate of crystals and when the metal undergoes plastic deformation due to certain strains, the crystals are deformed in the same general sense as the metal. This change of shape in crystals is accompanied by a process of "slip" or "gliding" by which layers of crystals slide over one another along certain gliding planes. When slip is severe or localized, the molecular disturbance at the slip surfaces increases the quantity of amorphous cement which has its genesis in the gliding action. Moreover, if internal shear results, deformation increases to such an extent that the steel becomes transformed from a crystalline condition to an amorphous condition in which crystal fragments are imbedded. As the process continues and as such amorphous metal is more brittle and less resistant to shock, the crystals begin to lose their strength and ultimately the crack or flaw started works its way across the entire section until rupture results with a bright, shiny, coarse fracture.

Intelligent attention must be given to design and dimensions as well as to the material, and the relation established between endurance and other physical properties, so that in order to resist fatigue this endurance limit should be as high as possible. This involves the making of the tensile strength as high as possible, consistent with the ductility required. In other words, ductility should be the lowest limit consistent with the use of the bolts. Too much stress in some cases has been laid on the requirements for ductility which have not been warranted and frequently 30-35 per cent elongation is specified when 16 per cent is ample. This again brings us to the point that when stresses in service are severe, high elastic ratio, quenched and tempered alloy steel is an absolute necessity.

Information obtained by endurance testing during the past several years undoubtedly has led and will lead to many changes in the selection of material for bolts.

DIRTY STEEL

Engineers are realizing more and more that steel intended for use in bolts for high pressure and high temperature service where high stresses of various kinds are encountered, must not be full of nonmetallic inclusions if a reasonably long life is to be expected.

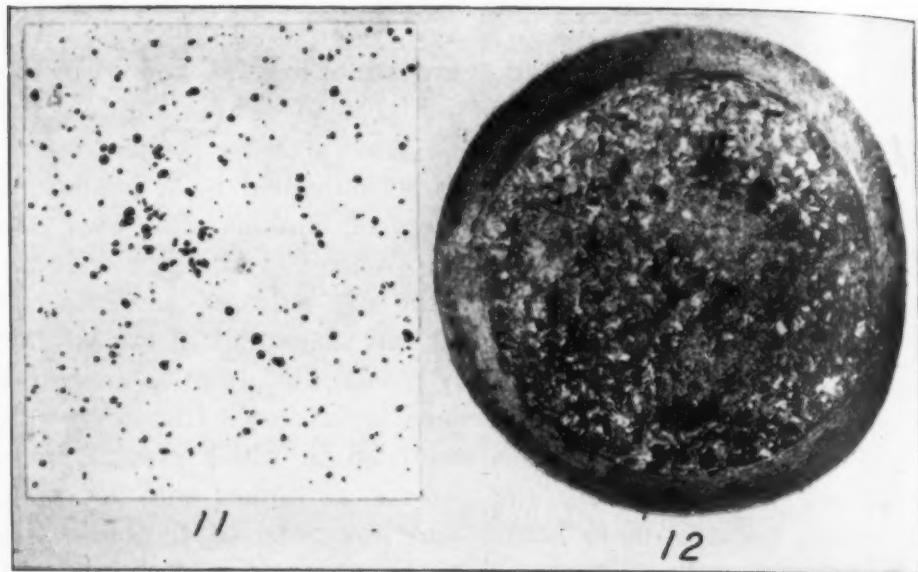


Fig. 11—Photomicrograph of a Specimen of Dirty Steel. Excessive Oxides of Iron and Rounded Gray Manganese Sulphide Inclusions. Unetched. 100x. Fig. 12—Photograph of the Fracture of a Steel Bolt Caused by Dirty Steel. Refer to Photomicrograph Fig. 11. 4x.

The importance of clean sound steel is now recognized by the fact that it is able to meet the exacting specifications for high class work. Dirt in steel is one of the problems that manufacturers must solve and guard against because it will cause premature failure of bolts in service. Inclusions in steel for bolts appear to act as local stress "raisers" and since they are probably hard compared with the steel matrix in which they are imbedded they may be considered as internal notches. If a nonmetallic inclusion is so shaped and so placed with respect to direction of stress application the local effective stress rises above the critical value, i. e. (the endurance limit) and we have the mechanism by which fatigue failure may start, even though the nominal computed stress for the bolt is below the actual endurance limit of the steel composing the matrix. Once started, fatigue failure proceeds from this minute crack in a manner well understood by the effect of impact on external notches, because it is a well known fact that a surface notch greatly increases the local stress over the nominal calculated stress. Therefore, internal notches such as those caused by nonmetallic inclusions have the same effect. Hence, dirty steel is unreliable under repetition of stress, and is one thing the designer cannot calculate, except by using a large safety factor. (13)

A series of endurance tests recently completed in bolt steel

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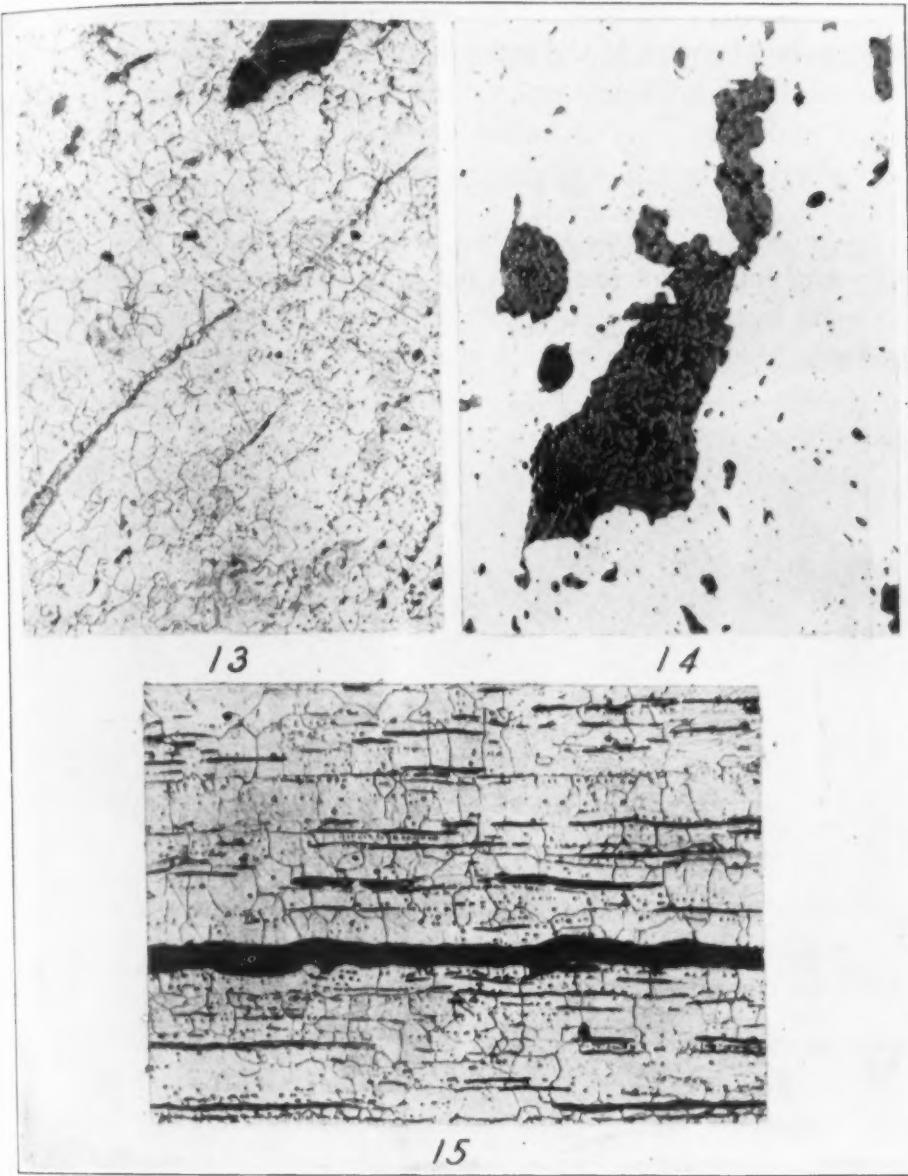


Fig. 13—Photomicrograph of Forged Carbon Steel Bolt which Failed in Service, Showing Slag Streak and Inclusions. Etched with Nital. 100x. Fig. 14—Photomicrograph of Slag and Silicate of Iron and Manganese Inclusions in a Bessemer Screw Stock Bolt Material. Unetched, 100x. Fig. 15—Photomicrograph of a Wrought Iron Bolt Showing Slag Streaks. Etched with Nital. 100x.

has shown a great difference between bars of the same material, handled in same manner and tested with same nominal stress, except that some were found to be dirty.

Users of steel who carry out the bend test have found surprisingly low ductility in steel containing dirt even though the ten-

sion bars were excellent. Therefore it is important that clean sound steel be used in the manufacture of bolts, for once dirty steel has solidified, nothing can be done to remedy it. See Figs. 11-12, 13-14 and 15.

EFFECT OF PHOSPHORUS AND SULPHUR

Another condition that has been discovered in this investigation is the use of screw stock not only as a material for nuts, but in some instances we have found it used in bolts as well, and we are sure that the use of this material is dangerous because of its

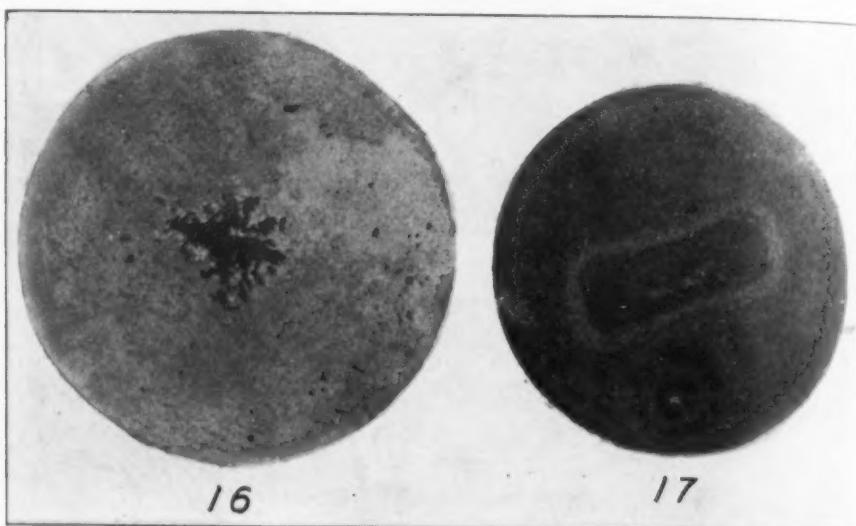


Fig. 16—Photomicrograph of Bolt Steel Showing Sulphur Segregation. Etched with Heyn's Reagent. Full Size. Fig. 17—Photomicrograph of Bolt Steel Showing Phosphorus Segregation. Etched with Stead's Reagent. Full Size.

treacherous brittleness especially at elevated temperatures. Our investigation has shown that numerous unexplained failures have been caused by high sulphur and phosphorus which in some cases is nearly three times what it should be.

Since the early days of steel chemistry these two elements have been the enemies of good steel. That sulphur makes the steel "red short" and that phosphorus makes it "cold short" and generally treacherous, are axioms of steel works practice. Not only practical observations but a large amount of scientific study supports these beliefs.

Phosphorus is treacherous as the strength of high phosphorus material varies as the speed of application of the loading. It is capricious since the same amount of phosphorus acts in different

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ways, and it is reasonably certain that steels containing high phosphorus are likely to be brittle under shock even though they have splendid ductility when tested statically.

One of the reasons for the capricious behavior of steels high in phosphorus is that in steel the phosphorus is combined with iron as a ferrophosphide, which in turn is alloyed with the residual iron. Consequently we have a direct alloy relation generally much intensified locally above the average condition because of a marked tendency of phosphorus to segregate in bands or streaks. This under repeated stress or shock results in cracking in the high phosphorus zones, subsequently travelling through the body of steel because of an unobstructed path through a crystalline mass. It is particularly noticeable that the effect of slight increases in phosphorus make themselves apparent by the influence on the shock resisting strength of steel, while the tensile strength remains constant. Figs. 16 and 17.

Sulphur is present in steel in two forms, i. e. iron sulphide and manganese sulphide of which the latter is most common. The sulphide of iron is present when sulphur is high and there is insufficient manganese present to react completely, and the residual sulphide remains molten and is deposited along the grain boundaries of the steel. This forms an intercrystalline film, which has little strength, and when such metal is put under stress, rupture takes place with a conchoidal fracture along the grain boundaries. In like manner, when molten metal containing high sulphur is passing from the liquid to the solid state, strains are set up through shrinkage, and the steel gives way along these films which cause shrinkage cracks and when solidified, this iron sulphide which has spread out in thin sheets, gives rise to zones of weakness when cold, and as there is little cohesion between the crystalline grains it will cause rupture at low loading when hot.

When sulphur is high and in the form of manganese sulphide it often segregates when combined with high phosphorus or slag to form "ghosts" which is a condition very detrimental to the quality of the steel. Fig. 18.

MANUFACTURE

Defects in bolts may be caused by segregation, piping, gas inclusions, seams, etc., and are certainly a source of worry to the manufacturer of bolts unless he has his steel making process stand-

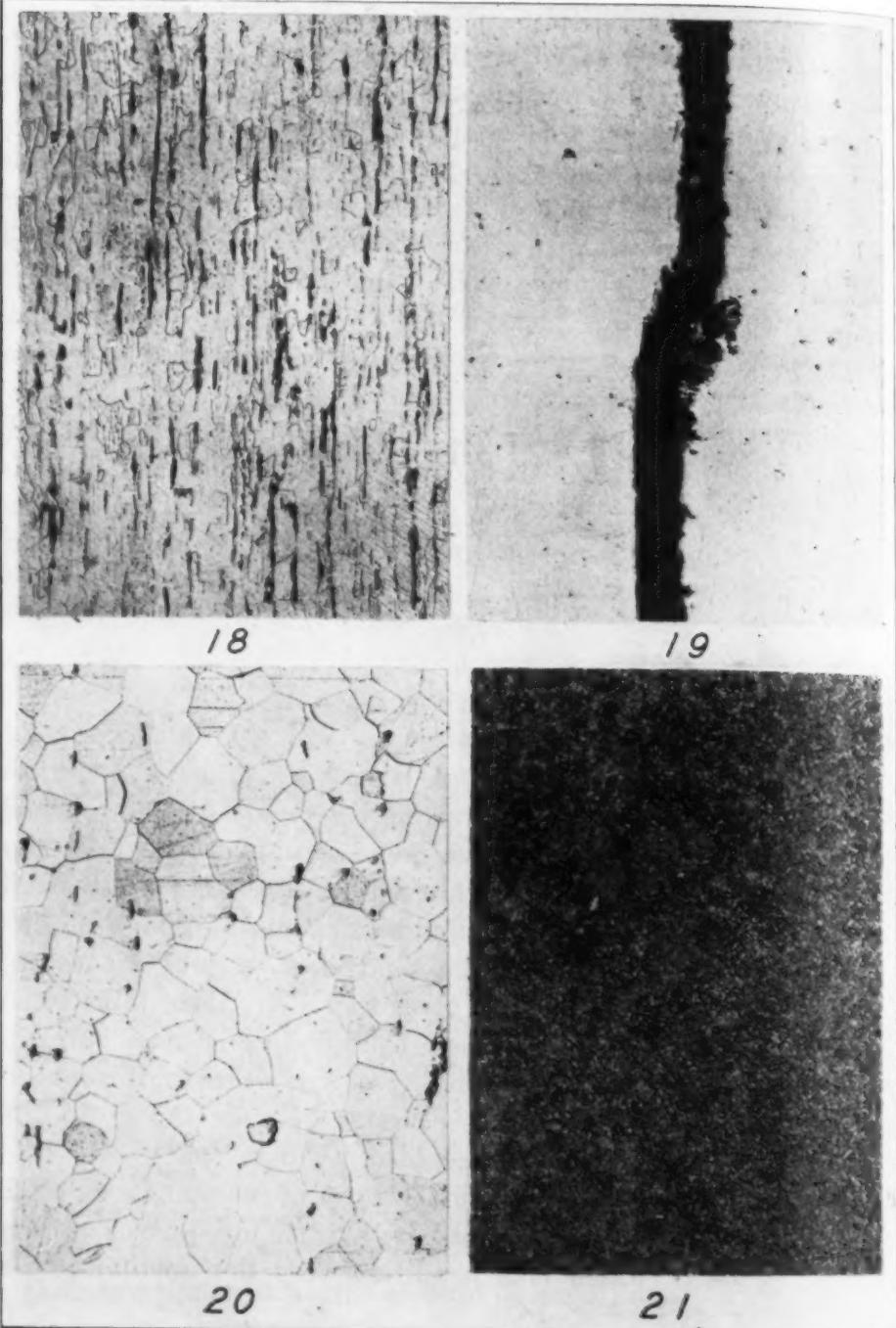


Fig. 18—Photomicrograph of a Section of a Carbon Steel Bolt Showing Streaks of Pearlite in Ferrite together with some Elongated Inclusions. Note the Banded Structure which is Indicative of Low Strength. Fig. 19—Photomicrograph of a Crack in Bolt Steel. Unetched. 100x. Fig. 20—Photomicrograph of a Low Carbon Steel Bolt Showing Streaks of Alumina and Silicate Inclusions. Etched with Nital. 100 x. Fig. 21—Photomicrograph of Alloy Steel Showing Homogeneous Structure. Etched with Nital. 100x.

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ardized and material given careful inspection. Poor manufacture leaves its mark indelibly stamped in bolts in the form of pipes, seams, segregations, etc., which are transmitted from the ingot to the billet and then to the rolled material and finally appear in the finished bolt. Such defects decrease the available area of the stressed part and act as starting points for cracks in the quenching operation or at least determine in part the direction of the path of cracks, especially when the bolts are subjected to vibration. Fig. 19. There are times when the steel mill fails to crop a sufficient amount of metal from the ingot and the pipe left in it is rolled into the bolt material causing a seam.

It is a well established fact that considerable of the defects which cause failure of bolt steel can be traced to improper heat treatment, and all good work done prior to heat treatment can be ruined, because the strains set up in improperly quenched steel may cause considerable trouble later on.

Machining operations such as cutting of threads on bolts may cause strains to be set up in the steel and reduce its strength, unless care is used in the operation.

It has been a matter of common knowledge for some time that the ordinary carbon steel bolt with the forged head has not been successful in steam power plants and in oil refineries and leaves much to be desired. For the reason that improper forging of headed bolts cause severe strains it is our opinion that bolts of this type should never be used for elevated temperature work.

ALLOY STEEL

It is generally recognized that when a metal is alloyed with one or more elements, the properties are changed in a remarkable degree. Therefore, by suitably alloying a metal, the properties of the resulting alloy possesses such profound qualities as to render it more adaptable for the purpose than for which it was originally intended. Figs. 20 and 21.

One of the most important objects in the manufacture of alloy steel is that the alloying elements enables us to decrease the injurious or undesirable properties and to intensify others that are preferred in the final product. Physical properties sought depend largely upon alloying elements, which are combined in such a manner with the metal that the separate constituents of the final alloy

cannot be distinguished, therefore, producing a homogeneous blending that defies detection of the constituent substances. This phenomenon indicates a strong combination of the constituent substances and defines the structure in an unmistakable manner.

The effect of carbon as a constituent of steel is well understood for by its virtues comparatively soft ductile iron may be strengthened to several times its original capacity or hardened to a similar extent. The presence of the alloying elements intensifies the effect of carbon in all the best qualities that it is capable of producing alone. These increases take form not only in the physical results such as tensile strength, elastic limit, dynamic strength, resistance to wear and fatigue, increased hardening power, lack of brittleness, etc., but also in purity, solidness and homogeneity of the metal. A visit to the scrap heap of some of our power plants and refineries will reveal many broken bolts which are not the result of misuse on the part of the user, but are due in many cases to the low grade of material used. See Table I and II.

Therefore it is evident that we must recognize approved methods and establish recommended practice for producing good material, for the main problem as we see it is to obtain steel of uniform chemical and physical properties heat after heat, and when this has become definitely standardized the proper heat treatment should be determined. Once the proper heat treatment has been standardized it should not be changed under any circumstances.

Table I
Tensile Test Report—Bolt Stock

Sample No.	Mark and Description	ELASTIC LIMIT (Yield Point)		Maximum Strength Actual	% Reduction	% Elong. in.	Fracture
		Actual	Per sq. in.				
LOW CARBON BOLT STEEL							
1	1x	6,950	34,750	12,230	61,150	69	34
2	2x	7,138	35,690	12,470	62,350	50	29
3	3x	7,298	36,490	12,638	63,190	48	28
HIGH SULPHUR SCREW STOCK							
1	15	8,838	44,190	13,800	69,000	62	36
2	25	9,296	46,480	14,024	70,120	60	33
3	35	9,132	45,660	13,796	68,980	66	35
WROUGHT IRON							
1	1w	6,080	30,400	10,150	50,750	37	20
2	2w	6,356	31,780	10,920	54,600	47	22
3	3w	6,700	33,500	10,720	53,600	39	21
ALLOY BOLT STEEL							
1	1CN/1200	21,640	108,200	27,144	135,720	64	22
2	2CN/1200	21,820	109,100	27,280	136,400	62	23
3	3CN/1200	22,000	110,000	27,560	137,800	60	22

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Table II
Results of Physical Tests on Alloy Steel Bolt Material

ENDURANCE TESTS—REVERSED BENDING IN MODIFIED FORMER MACHINE	
Unit Stress lbs. per sq. in.	Cycles of Failure
90,000	28,000
86,000	52,000
83,000	132,000
77,500	240,000
75,000	360,000
70,000	590,000
69,400	820,000
68,000	1,100,000
66,000	1,527,000
65,500	2,218,000
65,200	3,762,000
64,800	20,000,000*
64,500	1,020,000,000*

*Specimen did not fail.	
REPEATED IMPACT TEST, STANTON	
Steel hammer 4.5 lbs. weight fall through 2 inches	
Distance apart of supports, 45 inches	
Number of blows to failure, 5,200	
TORSIONAL TEST	
Proportional limit in torsion	69,300 lbs.
Modulus of elasticity	11,632,000 lbs.
CHARPY IMPACT TEST, AMSLER MACHINE	
Impact Bending	
Average 52 foot lbs.	
BRINELL HARDNESS	
B. H. No. 260-300	
TENSILE TEST	
Tensile Strength	135,800 lbs. per sq. in.
Yield Point	109,600 lbs. per sq. in.
Elongation in 2 inches	22 per cent
Reduction of Area	61 per cent

In this consideration it must be realized that everyone does not agree upon certain specifications, but regardless of this fact, we have today certain specifications as the standard A-96-25 of the American Society for Testing Materials that demand a high class alloy steel. It must be realized that there is no precedent that has been established for this class of work as the demands of today are far more exacting than at any time during the past.

HEAT TREATMENT

As the production of clean, sound steel is the first requisite, the second and of the same importance is the thorough and proper heat treatment of the steel so that the steel may possess the best physical properties of which it is capable.

In the heat treating process the speed and uniformity of heating are among the most important factors in the successful heat treating of bolt steel. The temperature and soaking time are important as well as the quenching media. Oil quenching baths should

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always be used, for they have the advantage of reducing the speed in cooling and there is less danger of cracks and strains being set up. The steel should be removed from the quenching bath before cold, and properly tempered, that is by "drawing" so as to relieve the strains set up and impart to the steel toughness together with a fine grain structure. Figs. 22, 23, 24 and 25.

A quality often described as "tough hardness" is especially desired and is one of the specific properties of alloy steel as

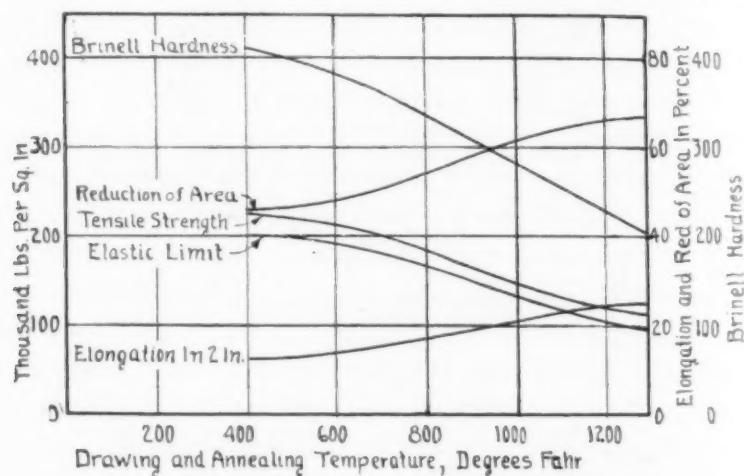


Fig. 22—Curves Showing Heat Treatment Chart for Alloy Steel Bolt Material.

measured by the bend test and reduction of area in the tension test. This so-called quality is in all probability due to the somewhat finer and denser structure of the microscopic constituents and their uniform distribution in the alloy steel. Therefore this dense structure is one of the main reasons for high physical properties and at the time when structural changes occur, it is in the best possible condition for these changes to take place.

INSPECTION

Constant and critical inspection should be maintained by the manufacturer of bolts in order that he may produce a standard quality product. Inspection standards should be adopted which in every case are paramount. The selling prices, the difficulties in manufacture and other considerations should be subordinated in a sincere effort to produce the best steel bolts for the purpose required.

The results of the strict application of this practice are evident

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in many small details that crop up in the metallurgical and manufacturing process. This inspection is carried out on all materials entering the works, before unloading, during course of manufacture and after assembly.

The laboratory should be concerned particularly with the quality of material and the steel to be used for stud bolts which should be carefully tested and inspected as follows:

(a) All steel for stud bolts entering the factory should be given a visual examination. Small sections cut from the bars should

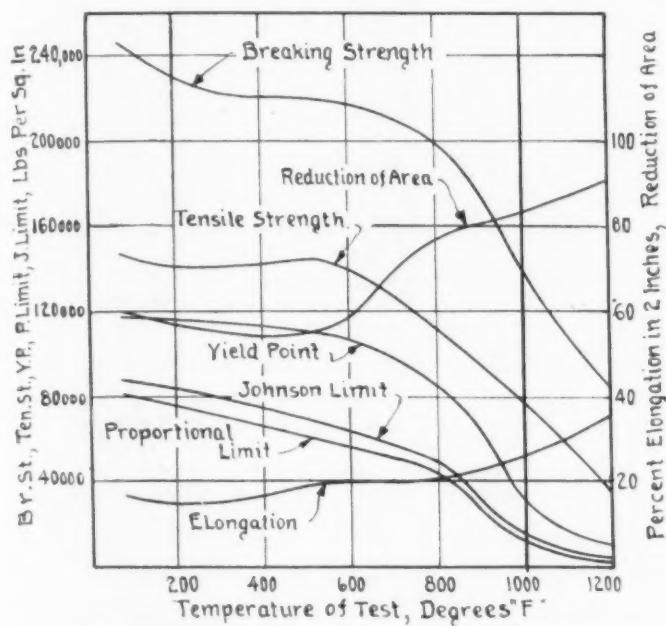


Fig. 23—Curves of Short Time High Temperature Tests on Alloy Steel Bolt Material Plotted in Accordance with Joint Research Committee's Specifications.

be subjected to the hot etch to determine whether steel contains cracks, seams, segregation or has been strained.

(b) Each bar should be stamped with heat number from the mill showing the melt so that mill inspection can be checked.

(c) The chemical analysis should be checked after which several bars should be cut into small lengths and heat treated in accordance with the standard practice, after which bars are tested in tension and impact and fractures carefully examined.

(d) If material has met specifications it is then placed in stock in special bins and marked with symbols which designate the heat of steel. The key to these symbols is kept in the laboratory

together with chemical analysis and physical tests so that it may be checked at any time.

(e) Brinell hardness tests may be made at any time throughout the course of manufacture in order to check heat treatment.

(f) Mechanical tests to be made by inspectors at the machining operation and at assembly.

In the first part of this paper it was stated that it was the

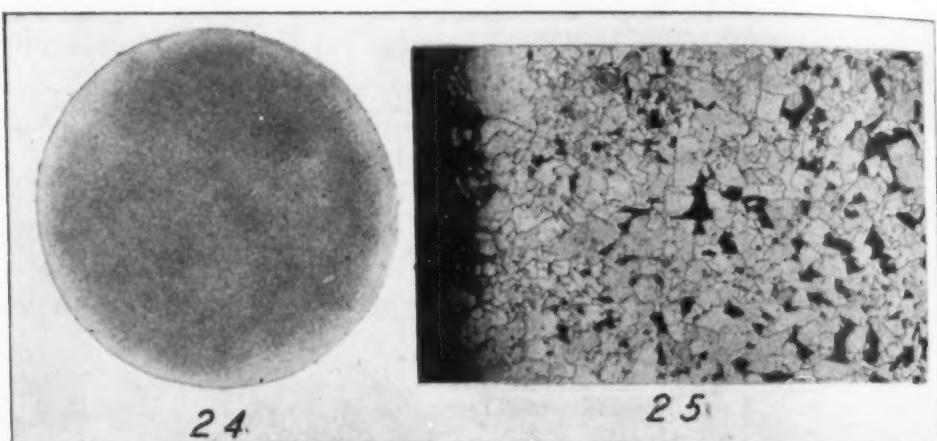


Fig. 24—Photomacrograph of the Decarburized Surface of a Bolt. Etched with 10 per cent Ammonium Persulphate. Full Size. Fig. 25—Decarburized Surface of Bolt. Same Specimen as Fig. 10. Etched with Nital. 100x.

idea of quite a few people that "steel is steel" and this may be so, but it requires constant study and investigation, separation, and selection, carefulness in handling, judgment in choice, determination of purpose and treatment and accuracy in carrying out this treatment, thus will production be maintained with a product that will be a source of pride to the company making it and a satisfaction to the consumer.

METHODS OF TEST

Certain tests have been carried out in this investigation from which conclusions have been drawn. These tests covered:

Endurance testing

Impact testing

Tension testing at elevated temperature (short time)

Tension testing at elevated temperature (long time)

Thermal expansion research

Design

Heat treatment

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Torsion tests

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Microscopic and macroscopic research.

A short synopsis of methods and machines used in these tests will be given as some of the apparatus is new.

ENDURANCE TESTING

In authors' laboratory the Farmer-type rotating beam endurance testing machine as modified by Professor Moore of the University of Illinois, is used.

This form of machine with two symmetrical loads has been used by many investigators, the first being Professor Sondericker of M. I. T. and later was described by T. M. Farmer, A. S. T. M 1919 and modified by Professor Moore.

Endurance or fatigue tests are made in these machines by taking a number of test pieces and commencing with a stress of somewhat above half the tensile strength of the material and the test piece run to destruction. The number of stress cycles to fracture is recorded on the counter. The stress is somewhat reduced on successive specimens until a total of 20×10^6 cycles is obtained without fracture. This is taken as the endurance limit, and in our opinion is a very desirable test for determining the strength of bolt steel. Fig. 27, shows chart of endurance limits.

IMPACT TESTS

For impact testing an Amsler impact testing machine was arranged for the Charpy test. This method of testing bolt steel is considered by the authors as one of the most important of the mechanical tests, as it affords a reliable indication of the resistance to deformation and especially when cohesion is small in relation to internal frictional resistance to distortion of the cohesive strength.

It is generally agreed that the following information can be obtained from impact tests:

- (a) It shows the influence of heat treatment more clearly than the tensile test.
- (b) It measures local injuries due to flaws, segregation, etc.
- (c) It measures the ability of steel to resist shock and shock ductility.

We find this form of test standardized in Europe and a great many users of quality steel in this country are adopting certain impact requirements without proper investigation and unless manufacturers are familiar with the impact value of their steels and

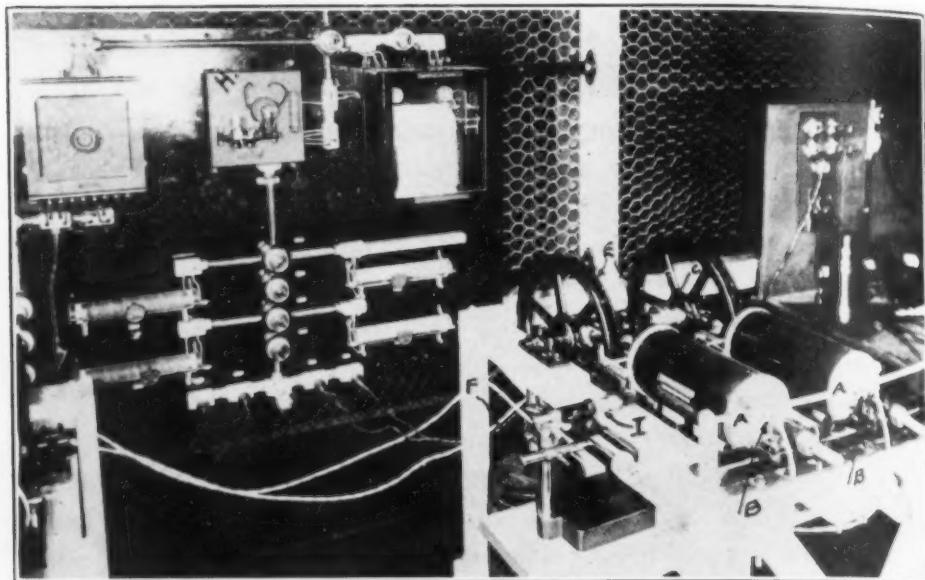


Fig. 26—Photograph of High-Temperature Long-Duration Test Apparatus.

know its limitations, they are likely to fail should they accept specifications without complete knowledge of the work in hand. Impact values can only be obtained for specifications by an extensive study of good and failed material.

HIGH TEMPERATURE TESTS (SHORT TIME)

The testing of metals at temperatures at which they are used in service is probably one of the most vital fields of engineering research and will in the near future be one of the most actively exploited fields of metallurgy in search of metals to withstand high temperatures. A cursory examination of scientific and technical literature will convince one of the extent of scientific interest in this subject and we believe it is one of the most serious problems confronting industry today.

Little need be said however, at this time regarding the testing of metals at elevated temperatures because the work of this laboratory has been published in the transactions of the various engineering societies, as this company was among the pioneers in

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this line of research. (14) However, it might be well to state that the apparatus used in making the tests is standard routine laboratory equipment and a part of the testing machine, and so located that it may be swung into place whenever needed.

LONG-TIME TESTS AT ELEVATED TEMPERATURES

When the symposium on the properties of metals was given before the A. S. M. E. in convention, in Cleveland, May 1924, one of the authors (14A) stated that a knowledge of the behavior of metals

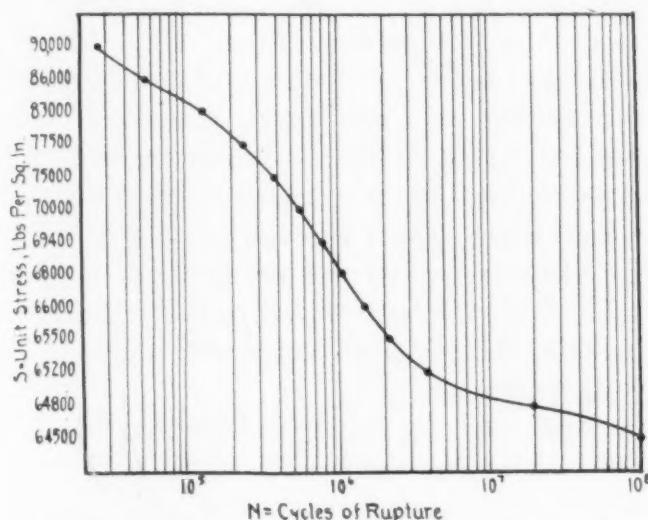


Fig. 27—Chart Showing the Endurance Limit of Alloy Steel Bolt Material.

at elevated temperatures over long periods of time would undoubtedly be of great technical importance for reason that long-time tests reported by investigators in England had tended to cast a grave doubt as to the validity of our ideas on yield point and elastic limit of certain metals in common use, and since design is based on yield point (the so-called commercial elastic limit) the matter becomes important.

We have noted in several cases of failed material that a gradual change of structure occurs after a lapse of time and this is one reason for failure of metals that have shown excellent results when tested in a short time at same temperature. Tests of short duration while of great value, are not always sufficient to indicate the behavior of a metal in service and it should be our aim to carry out such tests as will approximate the conditions of service. Because of the importance attached to securing a better knowledge of the

behavior of metals over periods of long duration at constant elevated temperatures and constant loads, we designed and constructed apparatus to carry out a systematic study of these properties. Fig. 26.

We believe we are among the first three laboratories in the United States to carry out a systematic investigation on this subject, which we began in 1924. (15)

Apparatus—The apparatus used in carrying out these tests consists of electrically heated furnaces "A" in which the test bars are placed which bars are then screwed into adaptors "B" attached to cables, these cables passing over drum "C". An 18-inch wheel "E" carries another cable "F" with load "G" suspended, making the entire system in a horizontal plane. The temperature control is obtained by an automatic controller "H" which keeps the temperature of the furnace constant during the test.

The sides of the furnaces are slotted and fitted with doors, through which the "creep" of the specimens is measured with a micrometer microscope "I" graduated to 0.01 millimeters, so that small movements of the material under test is determined. Eight units are now in operation.

We have duplicated the findings of Mr. French of Bureau of Standards (16) and quote from his discussion as follows:

"The total flow producing fracture when low carbon steel is subjected to a fixed total load in tension at approximately constant temperature takes place in three distinct steps, the importance of which may vary with the applied load and temperature. The three steps of flow are as follows:

- (a) An initial flow.
- (b) A secondary flow at a fairly constant rate which is also considerably less than the rate during the first and third period.
- (c) A final rapid flow before rupture.

"As the constant applied load is increased, the initial flow and the rate of flow in the second period increases and life of steel decreases. The final rapid flow begins when the reduction in cross section accompanying appreciable elongation has raised the unit stress to a definite value at each temperature."

Therefore, we believe that at each temperature there is a particular stress below which the metal may flow (1st period) and that it continues to deform under continuously applied stress, but

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with time the flow will drop to zero and continue there (2nd period) above the stress the metal will flow rapidly till final fracture (3rd period.)

We believe that for each temperature of steel tested there is at this temperature a stress which if exceeded will cause continuous flow and finally fracture, though bolts may show satisfactory service operating at this temperature for long periods.

It was therefore necessary in our research to determine the stress at each temperature that could be applied to bolts without

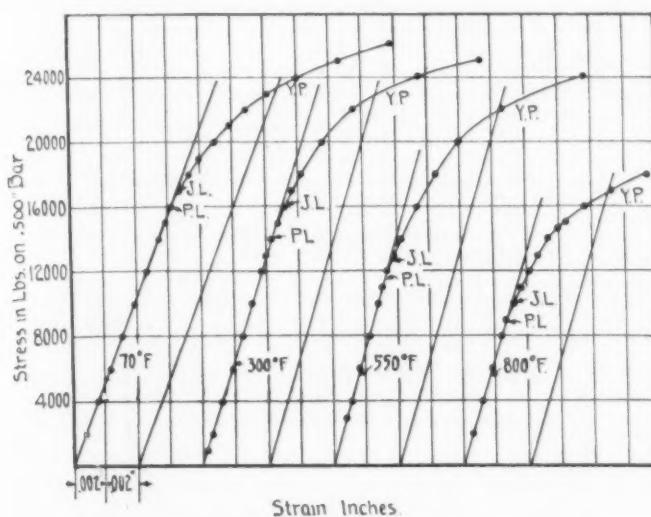


Fig. 28—Stress-Strain Curves for Alloy Steel at Temperature of 70-300-550-800 degrees Fahr. The Extensometer used Measured Increments of Strain to 0.00001 Inch.

appreciable deformation, and from results of this work we are assured that our material will stand the severe service of 1000 degrees Fahr., without deformation over long periods provided the allowable stress is not exceeded.

Troendly and Pickwell's paper (12) states that as far as they are aware no one has devised a way to obtain the elastic limit at elevated temperature. The authors believe they have fairly well solved this problem as well as Mr. French (17) and Messrs. Lynch, Mochal and McVetty, (18) our assumption being based on the checking of the maximum allowable stress from the "creep" tests with the proportional limit of the short time tests. Of course very delicate apparatus had to be designed to determine the proportional limit and in one instance the reading being to 0.000004 inch. The extensometer used in our investigation is accurate to 0.00001 inch.

Certain investigations made and results published during the past year are undoubtedly going to throw considerable light on this work. (15) (16) (17) (18) (19).

We wish to emphasize the importance of the tests under dis-

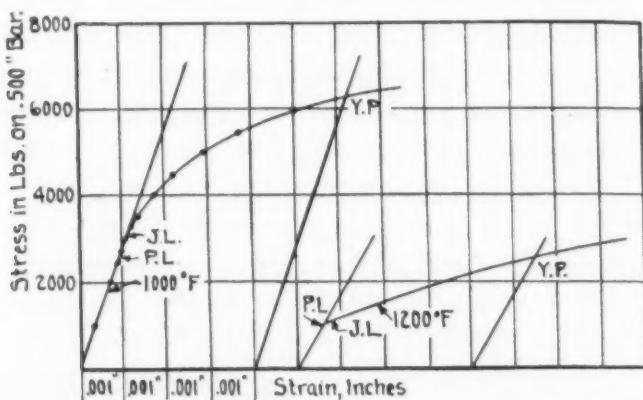


Fig. 29—Stress-Strain Diagram for Alloy Steel at Temperatures of 1000 degrees—1200 degrees Fahr.

cussion because the rapid decrease in strength of metals at elevated temperatures is not greatly appreciated as yet, for it is not generally recognized that the time factor is of great importance in

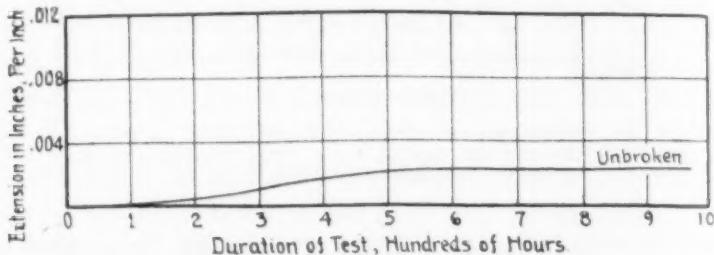


Fig. 30—Long Duration Tests of Alloy Steel Bolt Material at 750 degrees Fahr.

determining the maximum allowable stress. We believe, however, that in the near future from results of these tests a relation will be established between long and short time tests that will provide the engineer with a rapid method of determining the strength of his metals at the temperature to which they will be subjected and the result will be that the best materials for specific application will be obtained. Figs. 23, 28, 29, 30 and 31.

DESIGN

At the request of several engineers we have carried out a series of investigations into the fact as to whether full threaded bolts would show better properties than ordinary stud bolts.

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The facts brought out were that first an ordinary stud bolt with few threads under the face of the nut causes the entire strain in the bolt to be localized on this section because it is of reduced diameter, (i. e. the root of thread) and for this reason permanent deformation will take place under the nut before any appreciable amount of stretch has taken place in the heavy section, and second-

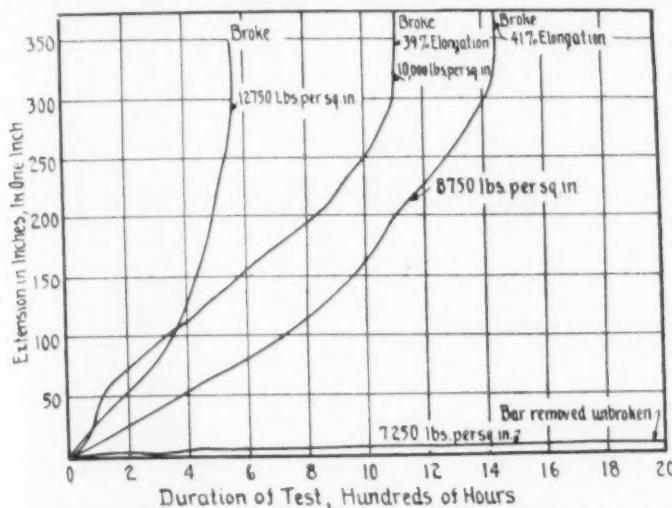


Fig. 31—Long Duration Tests of Alloy Steel Bolt Material at 1000 degrees Fahr.

ly, that a full threaded bolt with a cross sectional area the same throughout its entire length would have a uniform stress distributed over it and this stress not localized in a few threads as in the ordinary stud.

Tests were made on bolts 22 inches in length and were set up with flanges and nuts and the entire system placed in a testing machine. The gage lengths were laid off as shown in the diagram after which the load was placed on them. Fig. 32.

In each and every case the ordinary stud bolt failed in the section in which the few threads were exposed below the nut, while with the full threaded bolt failure resulted at different locations in the various bolts tested, and the point of failure was determined by any slight imperfection due to machining or due to a small non-metallic inclusion, which slightly reduced the cross sectional area.

In the ordinary stud bolt the entire elongation as shown in Fig. 32 was in the threaded section and this clearly shows that the stress was localized. In the full threaded bolts the elongation was evenly distributed over the entire length of the bolt which clearly shows that unit stress was well distributed. For example, in a $3/4$

inch ordinary stud bolt the unturned portion of the bolt has a diameter of 0.750 inch and an area of 0.4418 square inches, while the diameter at the root of the thread in the threaded portion is 0.620 inch and the area 0.3019 square inches which results in a difference in cross sectional area of 0.1399 square inches, and with 140,000 pounds per square inch steel there is a difference of 10,000 pounds per square inch between the heavy section and the rest of the thread. This conclusively proves that a load greater by 10,000

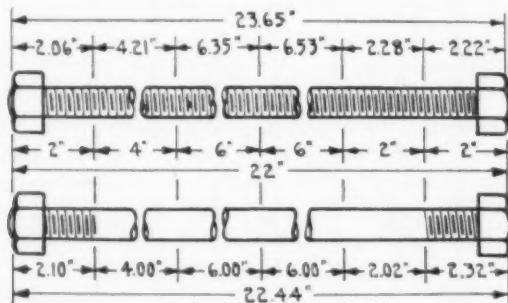


Fig. 32—Comparison of Design of Studs Bolts.

	Full Thrd. Bolt	Ord. Stud. Bolt
Tensile Strength	136000	128000 lbs. Sq. in.
Elastic Limit	112000	103000 lbs. Sq. in.

Fracture in every Case in the Ordinary Stud Bolt was in the Threads Exposed Under the Nut. In full Threaded Bolt Fracture Happened at the Weakest Section, i. e. where there was Heavy Tool Mark or Slight Flaw.

pounds per square inch is necessary to stretch the unthreaded portion, and certainly results in localizing the stretch or permanent set as the case may be in the threaded section.

Elongation of bolts when tested as full size bolts should not be confused with elongation as shown by the ordinary tensile test bar as the testing of the ordinary turned down test bar will always show a greater elongation than when testing full size bolts. It will be noticed from the diagram that elongation in full threaded bolts is much greater than in ordinary studs.

A very careful examination was made of full threaded bolts to determine if any strains were set up due to cutting of threads, but from the results of both physical and metallographic tests none were found.

The nuts and studs were carefully examined after failure to determine the action of the loading upon the threads and in no case did we find stripped or torn threads.

Several recent service tests in large power plants operating at elevated temperature and high pressure have confirmed these

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Fig. 34—Photofinished Carbon

findings and certain fittings ordinary sh... keeping the

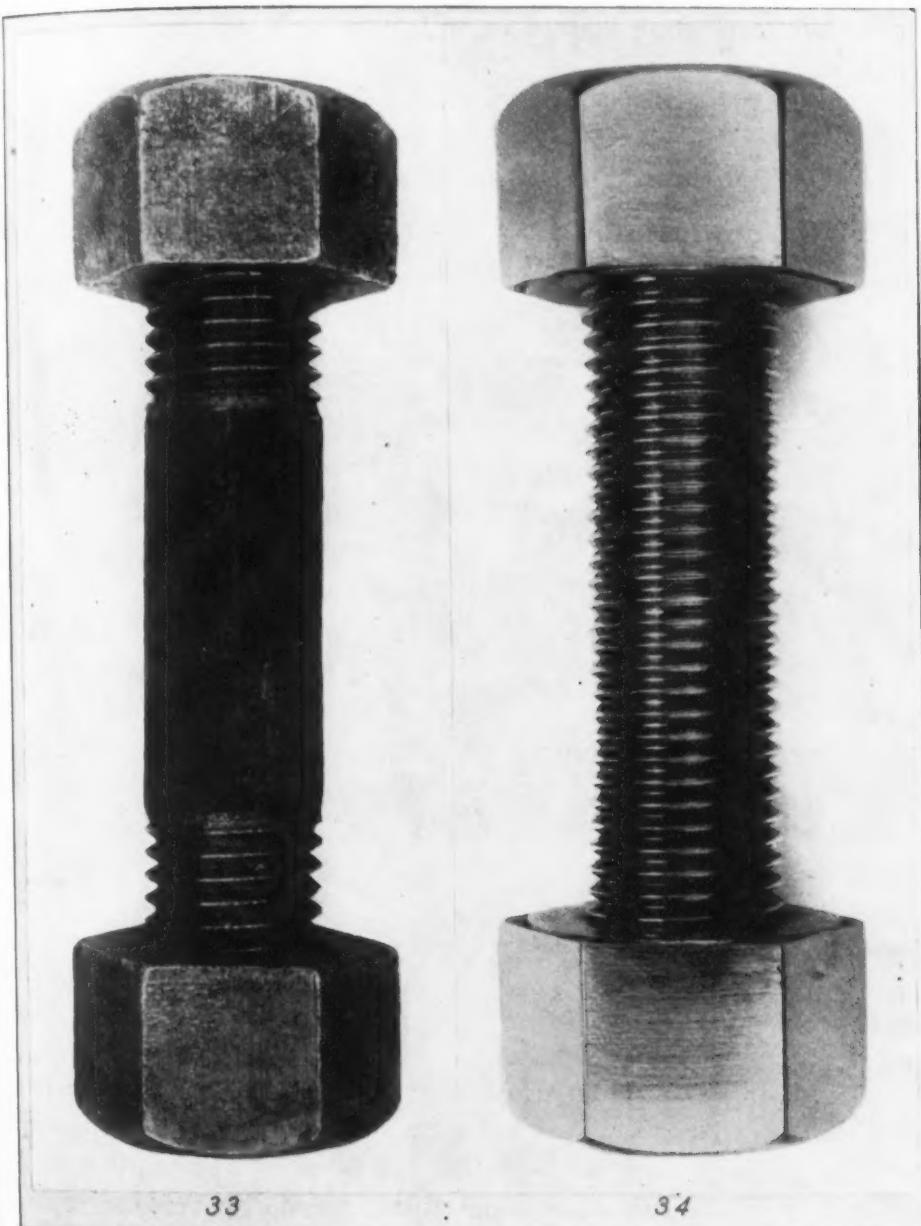


Fig. 33—Photograph of Stud Bolt with Threads only on End and Cold-Punched Nuts.
Fig. 34—Photograph of Full length Threaded Alloy Steel Stud Bolt Equipped with Semi-finished Carbon Steel Heat Treated Nuts. $5/7$ Actual Size.

findings and the report of one submitted to A. E. S. C. stated that certain fittings operating at 750 degrees Fahr. were supplied with ordinary shank stud bolts, and gave a great deal of trouble by not keeping the bonnets tight, but when replaced with full length

threaded steel stud bolts no further trouble occurred. Figs. 33 and 34.

The bolt material and size were the same in each case.

NUTS FOR STUDS

With regard to nuts we recommend a medium carbon heat

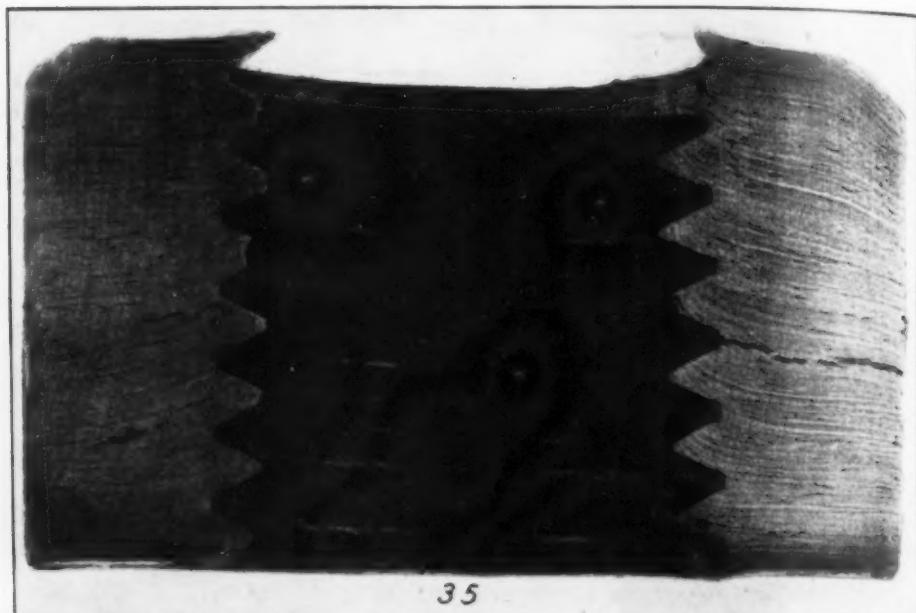


Fig. 35—Cold-Punched Nut Containing High Sulphur After Several Months Service. Note Strain Lines Caused by Cold Punching. This condition is very Common in Power Plants. Etched with Saturated CuCl in Cone. HCl. 4/5 Actual Size.

treated steel nut and not the ordinary cold-punched high sulphur nut for reasons as follows:

First, it has a modulus of elasticity and coefficient of expansion that compares well with the stud; second, because on account of this they will not stick as the ordinary cold-punched nuts do after being in service for some time; third, by the use of this type of nut a great amount of trouble is eliminated due to the poor manufacture and workmanship that appears in the cold-punched nut which in numerous cases are found to be wrought iron or high sulphur screw stock, and it is impossible to inspect each nut. Fig. 35 and 36. While the strength of the ordinary cold-punched nut is satisfactory the conditions as set forth make their use detrimental.

Of late we hear of the use of case hardened nuts, but if one gives a moment's consideration to this they will see the fallacy of

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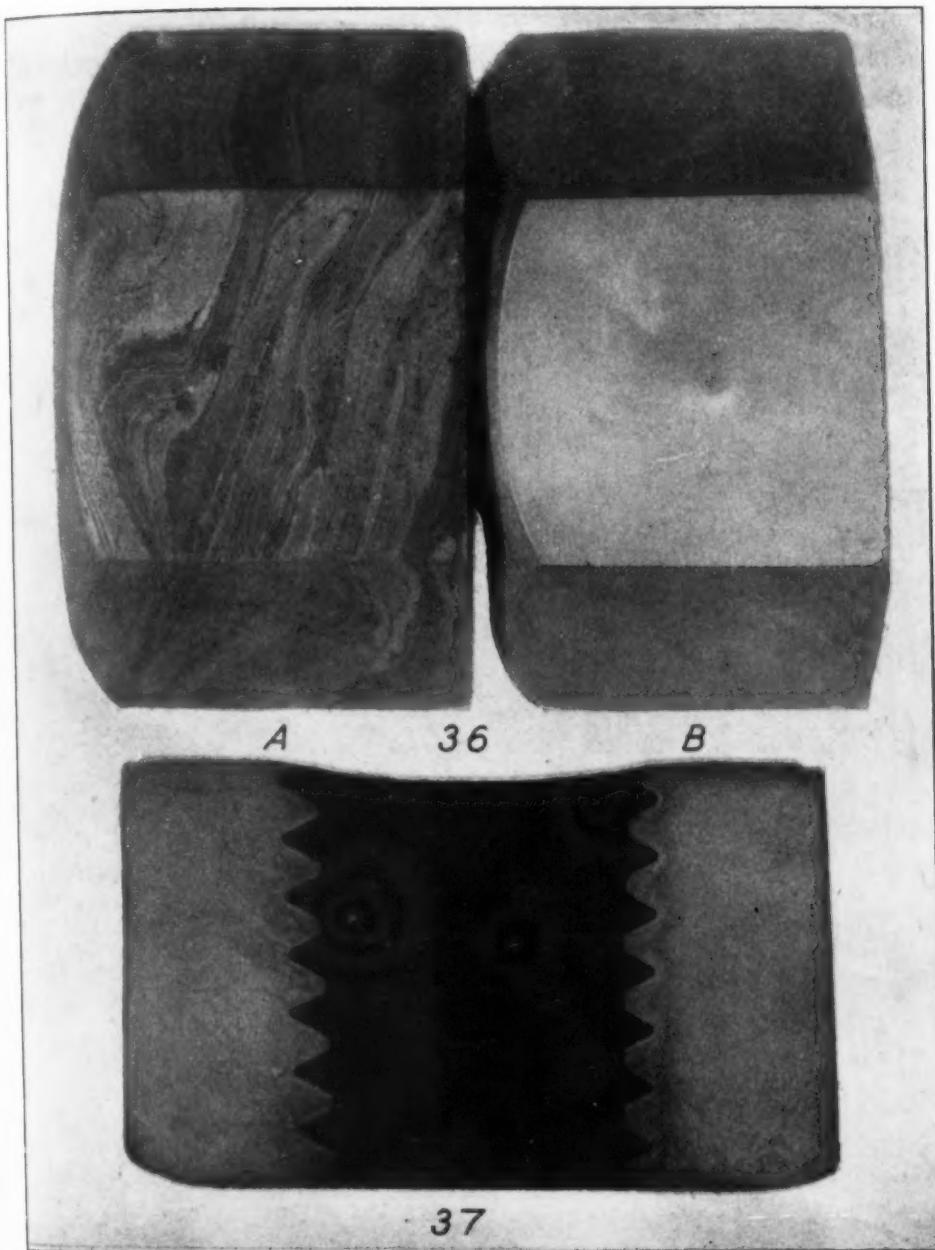


Fig. 36—Photograph "A" Shows Cold-Punched High Sulphur Nut in which the Layers of Slag are Readily seen. This is an Example of What is Found in Some High Pressure Installations. "B" is a Carbon Steel Heat Treated Nut as Recommended. Etched with Saturated CuCl in Conc. HCl. (Concentrated). Fig. 37—Photograph of a so-called Case Hardened Nut which is in Reality only Surface Hardened. Note the Flatness of Threads. Etched with Ammonium Persulphate. 2x.

the situation is evident even though it has some advantages. In the first place, case hardening causes brittleness, and is only used where it is necessary to resist abrasion and wear; and as the thread

of nut must be machined before it is case hardened, there is little doubt that the points of the thread are very likely to be brittle and break off when in service. Again, due to the high heat and

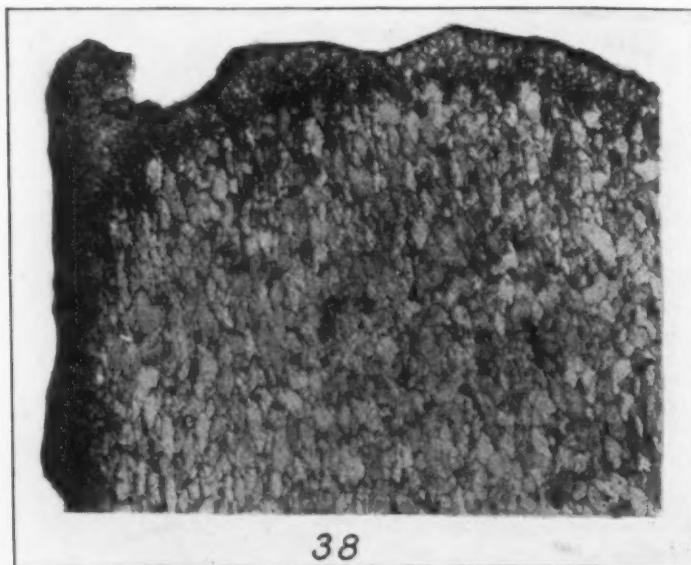


Fig. 38—Photograph of Section of Thread of so-called Case Hardened Nut in which the Depth of Case is Shallow. Note Particularly the Deformation of the Crystals Caused by Cold Work. Etched with Nital. 100x.

prolonged soaking necessary in case hardening, the core of the nut is effected to such an extent that it is a weak brittle material,

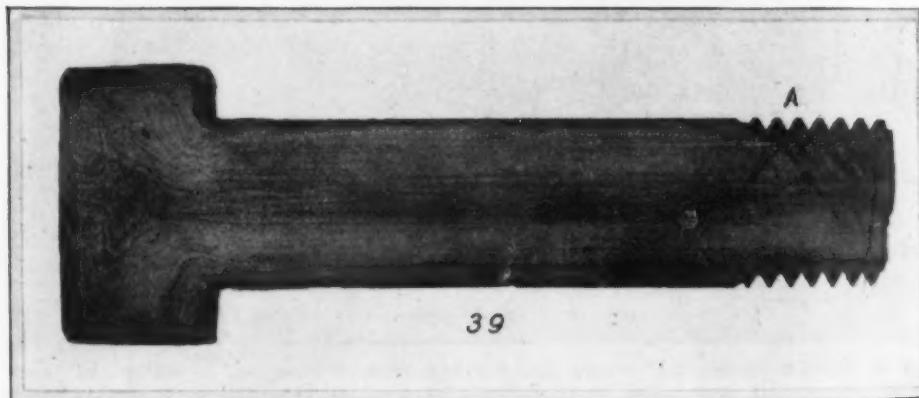


Fig. 39—Photograph of a Section of Carbon Steel Bolt after Failure in Service. The Bolt Failed just Below Point A and Section Above A plainly Shows Strain Lines. Etched with Saturated CuCl in Conc. HCl. $\frac{1}{2}$ Actual Size.

and is not able to withstand the required stress placed upon it in service, fatigues and becomes very brittle. Furthermore, in carrying out our investigation we have in a number of instances found

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Fig. 40
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the so-called case hardened nut only to be surface hardened (and that on the top and on the threads) with cyanide. Figs. 37 and 38.

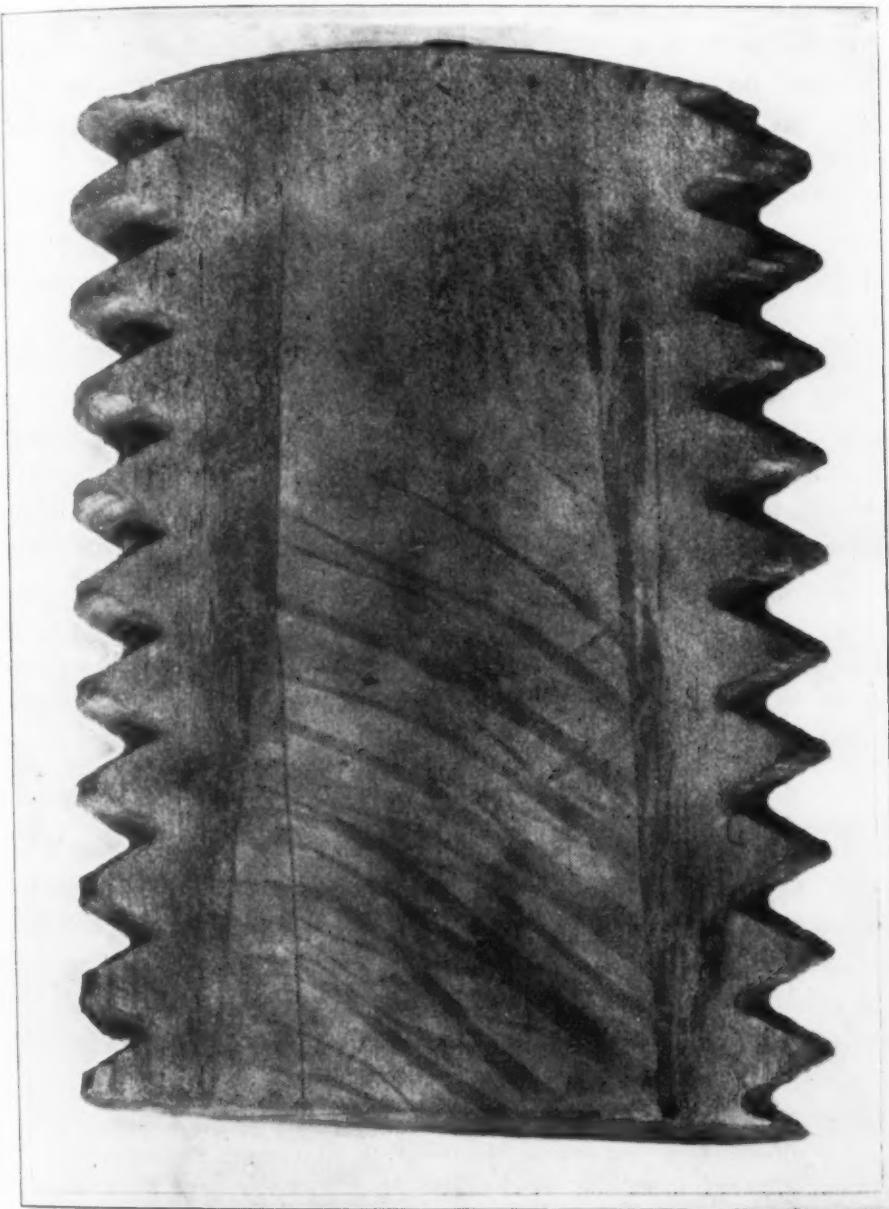


Fig. 40—Photomicrograph of Section of a Failed Bolt and Shows Strain Lines Caused by Tension, Bending and Torsional Stresses. Etched with Saturated CuCl in Conc. HCl. 6x.

All the advantages claimed for case hardened nuts may be had without its bad effects in the medium carbon heat treated steel nut.

METALLOGRAPHIC EXAMINATION

If bolts are subjected to stress which produces strains, and these bolts are highly polished and etched after being strained, very definite lines will appear in the surface of the polished bolt, which lines can be used to establish regions of highest stress concentration, and the type of stress as well as the approximate magnitude of the factor of concentration.

These lines indicate the highest stress concentration and if the force of the stress is determined experimentally, the comparison can be made to establish the magnitude and type of stresses set up in bolts after being assembled in valves or fittings.

This method of testing the weakness of bolts is not confined to any particular type of problem and is applicable to any bolt material as to the state of stress at the point under consideration.

The principal stresses are shown by the lines and express in a complete way the bending and shearing stresses, etc., which are readily seen from their direction and magnitude. Figs. 39 and 40.

This method was originally discovered by Dr. Fry of Essen, and applied to mild steels, but in our work we were able to develop this method so that it is applicable to all grades of bolt steels and by its use we are enabled to locate permanently strained areas in bolts in a simple manner.

CONCLUSION

In closing we wish to say that the problem of the proper material for bolts has been a difficult one to solve but by gradual development and elimination, we have at last obtained the ideal steel and from results of our tests both in service and laboratory it is evident that this steel will solve the bolt problems of high pressure and high temperature work.

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2. V. T. Malcolm, Discussion of Orrok and Morrison paper; *Transactions, American Society of Mechanical Engineers*, Vol. 44, page 1174, 1922.
3. Symposium on Properties of Metals at Elevated Temperature; *Proceedings, American Society for Testing Materials*, Vol. 24, 1924; *Transactions, American Society of Mechanical Engineers*, Vol. 46, 1924.

(Continued on Page 299)

THE DECOMPOSITION OF THE AUSTENITIC STRUCTURE IN STEELS—Part I.*

The Decomposition of Austenite During Quenching

BY RALPH L. DOWDELL AND OSCAR E. HARDER

Abstract

This is the first of a series of papers under the general heading of The Decomposition of The Austenitic Structure in Steels. This particular paper deals with the general plan of the investigation, the steels used, and, finally, the decomposition of austenite during quenching. The decomposition during quenching is studied under two headings; first, the ordinary quenching conditions, and, second, a special consideration of high stresses produced during quenching. The later papers will deal with the effect of submersion in liquid oxygen on the decomposition of austenite; effect of tempering (drawing) on the decomposition of austenite, Part I in which the operations are carried out at normal stresses and Part II, which is the subject of another paper, pays special attention to the effect of stress on the tempering changes; X-ray studies of the decomposition of austenitic structure in steel; and, finally, a paper in which there are proposed certain theories of hardening and tempering of steel.

PURPOSE OF THE INVESTIGATION

AT the present time there is a large amount of research work being done in correlating various physical and microscopic properties with the mechanical properties of steel. These investigations together with those in the past have led to a great deal of discussion on the mechanism of hardening and tempering steel and on the nomenclature of some of the microconstituents produced in the hardening and tempering of steel.

One of the purposes of this investigation was to try to establish the identity of the microconstituents produced when the austenitic

*This and the following articles on The Decomposition of the Austenitic Structure in Steel are based on a manuscript submitted by Ralph Lewis Dowdell in partial fulfillment of the requirements of the Graduate School of the University of Minnesota for the degree of Doctor of Philosophy. O. E. Harder, in charge of research. The introductory article of this series appeared in the January, 1927, issue of *TRANSACTIONS*.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, Dr. R. L. Dowdell is assistant professor of metallography and Dr. O. E. Harder is professor of metallography, University of Minnesota, Minneapolis.

structure decomposes on quenching or on tempering. Another purpose of this work was to investigate the formation and decomposition of austenite when subjected to stress.

Dr. John A. Mathews¹ recently gave considerable experimental evidence which indicated that, under most conditions, more austenite is retained at room temperature after oil quenching than after water quenching. He stated in the conclusion of his lecture that: "It is believed that a deeper investigation of hardening stresses rather than quenching rates may prove the key to the matter and possibly some future Howe lecturer will give the answer."

The theories advanced for explaining the mechanism of the hardening of steel are quite numerous and are largely postulations with incomplete and in many cases no experimental evidence. Since the whole hardening theory should be directly connected with the decomposition of austenite, it was believed that any new experimental evidence might add further light to this theory and thus improve the important industrial heat treating operations.

PLAN OF PRESENT INVESTIGATION

The principle purpose of this investigation has been to study the decomposition of the austenitic structure in quenched steels. This has necessarily involved a study of the conditions under which an austenitic structure is obtained; a study of the character of the austenitic structure, the condition under which the austenite is transferred into other structures, and the various factors influencing this transformation; and, finally, the study of the character of the products produced by the decomposition of the austenitic structure.

The main divisions of this investigation are given below:

1. Find the effect of quenching on the retention of the austenitic structure of high carbon and of several alloy steels.
2. Determine the stability of these austenitic structures at low temperatures.
3. Determine the stability of these austenitic structures on tempering for sufficiently long periods of time to more nearly approach equilibrium conditions than has been obtained in previous investigations.

¹Second Annual Henry Marion Howe Memorial Lecture, delivered at the New York Meeting of the American Institute of Mining and Metallurgical Engineers, February 16, 1925.

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Steel No.	Type
1. Cobalt-Cr	
2. Hadfield M	
3. Bain C-Cr	
4. High Spee	
5. Nickel Spe	
6. Carbon ..	
7. Cr Magnet	
8. Finishing	
9. Saw Blade	
10. High Carb	

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4. Determine the effect of mechanical stress on the stability of austenite.
5. Determine the effect of a combination of mechanical stresses and tempering on the stability of austenite.
6. Identify the decomposition products of austenite produced by various treatments.
7. Correlate the space lattices and their changes with the different microstructures and their transformations.
8. Determine experimental evidence to aid in explaining the mechanism involved in the hardening of steel.

STEELS INCLUDED IN THE INVESTIGATION

In the selection of steels included in this investigation it was necessary to select steels which could be put into the austenitic condition and, preferably, wholly into the austenitic condition. As a result certain steels were selected from those on the market and others were especially prepared to have compositions so that they would represent the different types such as carbon, chromium, nickel, manganese, cobalt-chromium, and tungsten.

In the following pages the chemical composition, general description, microstructures, and the preparation of the test specimens will be discussed.

Chemical Composition—The compositions of the important elements, other than iron, of the steels used in the investigation are shown in Table I.

Table I
Compositions of Steels Used

Steel No.	Type	C	Mn	Si	Co	W	Cr	V	P	S	Ni
1. Cobalt-Cr Magnet	.0.86	0.13	.16	13.66	...	9.31	...	.015	.041	...	
2. Hadfield Mn	1.37	11.88	.66	...	...	...	...	.097	...		
3. Bain C-Cr	2.22	0.36	.50	...	...	10.56	...	...	...		.03
4. High Speed	0.76	0.07	..	...	20.0	4.38	.86	.019	.002	...	
5. Nickel Spec.	0.99	0.04	.68	...	...	...	...	.033	...	22.57	
6. Carbon	1.35	0.24	.23	...	...	...	...	...	...	...
7. Cr Magnet	0.97	0.74	.33	...	...	2.87	..	.031	.005	...	
8. Finishing	1.37	0.20	.30	...	5.91	0.56	..	.020	.040	...	
9. Saw Blades	0.98	0.50	..	...	1.25	0.25	..	..	..	...
10. High Carbon	2.66	0.22	.19	...	...	...	..	.016	.020	...	

General Description of Steels—Steels Nos. 1, 2, 4, 6, 7, and 8 are used considerably in industry. Steel No. 3 was made by E. C. Bain² for his researches on chromium steel and it was through his courtesy that this steel was used. It is one of the types of semi-

²TRANSACTIONS, American Society for Steel Treating, 1924, Vol. 5, pp. 89-101.

high speed steel. Steels Nos. 5 and 10 were made by the writers, but are of a composition unsuited for most purposes other than research. These two steels were melted in an electric resistor carbon furnace in plumbago crucibles. After melting, they were cast into iron molds preheated to a red heat. The castings came out very sound, but were considerably segregated. However, after forging and annealing most of the segregation was eliminated. The forging of these steels was extremely difficult and great care had to be exercised to avoid overheating them. It was found necessary in forging steel No. 10 to use exceedingly light blows under a steam hammer.

Table II shows the sizes of stock before and after forging, the subsequent annealing treatment and the dimensions of the machined specimens.

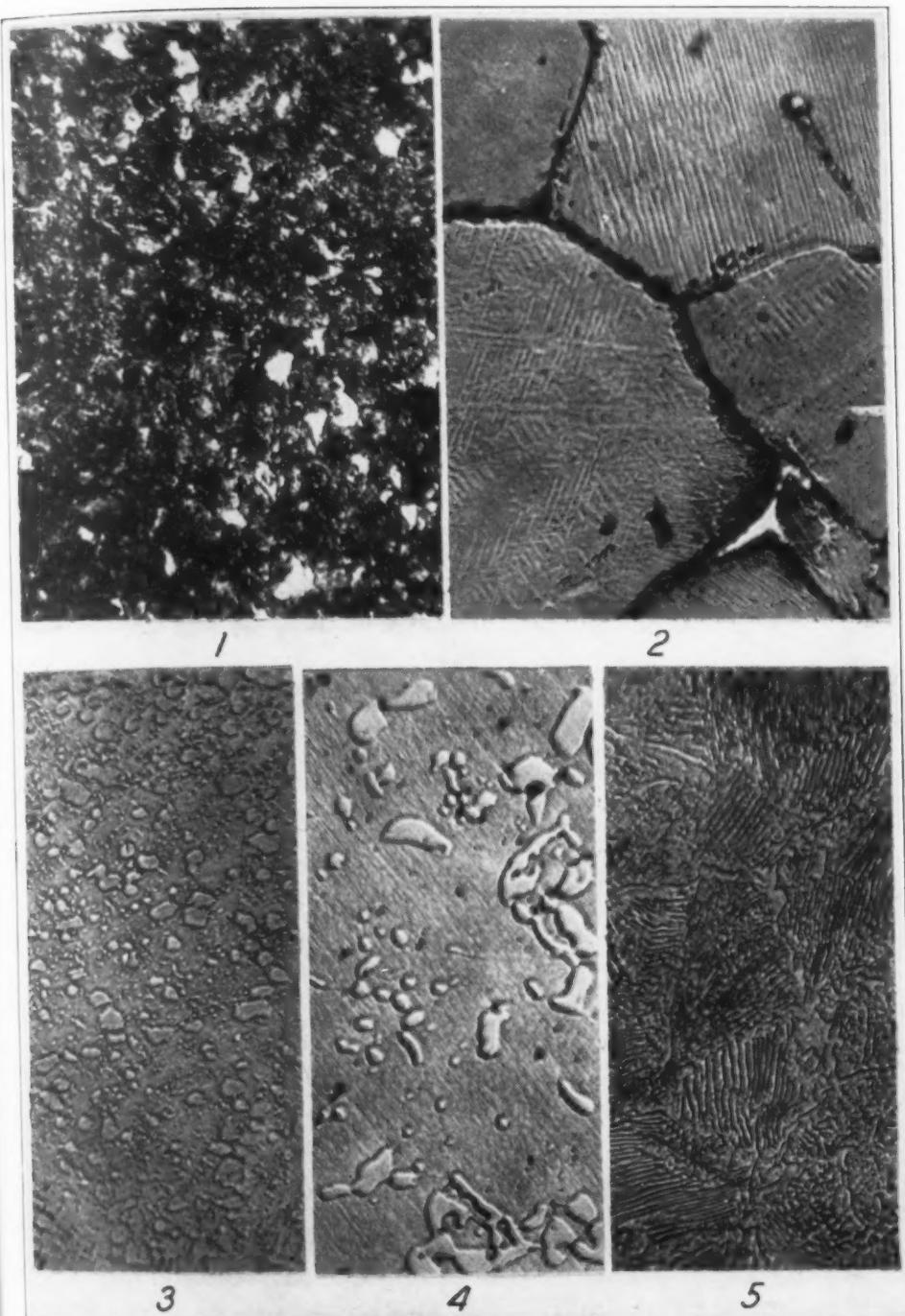
Table II
Sizes of Stock Before and After Forging, the Subsequent Annealing Treatment and the Sizes of Machined Specimens

Steel No.	Size as Rec'd or as Cast	Size after Forging	Annealing Temp. °C.	Time Min.	Sizes of Machined Specimens
3	$\frac{3}{8}$ " square	Upset to disc $\frac{9}{16}$ " by $\frac{5}{8}$ " high	1000	30	Cyl. .35" Diam. Cyl. 3.5" Length Ring $\frac{9}{16}$ " inside d. $\frac{1}{8}$ " wall thickness $\frac{1}{4}$ " width
5	Cast button $\frac{3}{4}$ " square	$\frac{1}{2}$ " round	about 900	0	Cyl. same as above
6	1" round	.45" round	800	30	Cyl. same as above
8	1" round	$\frac{1}{2}$ " round on power hammer	1000	30	Cyl. 1" diam. x 1" height Rings as above Cones 1" base diam. altitude $1\frac{1}{2}$ "
10	Cast $1\frac{1}{4}$ " square	$\frac{1}{2}$ " round 1" round on power hammer	800	30	Cyl. .35" Diam. Cyl. 3.5" Length Cones as above

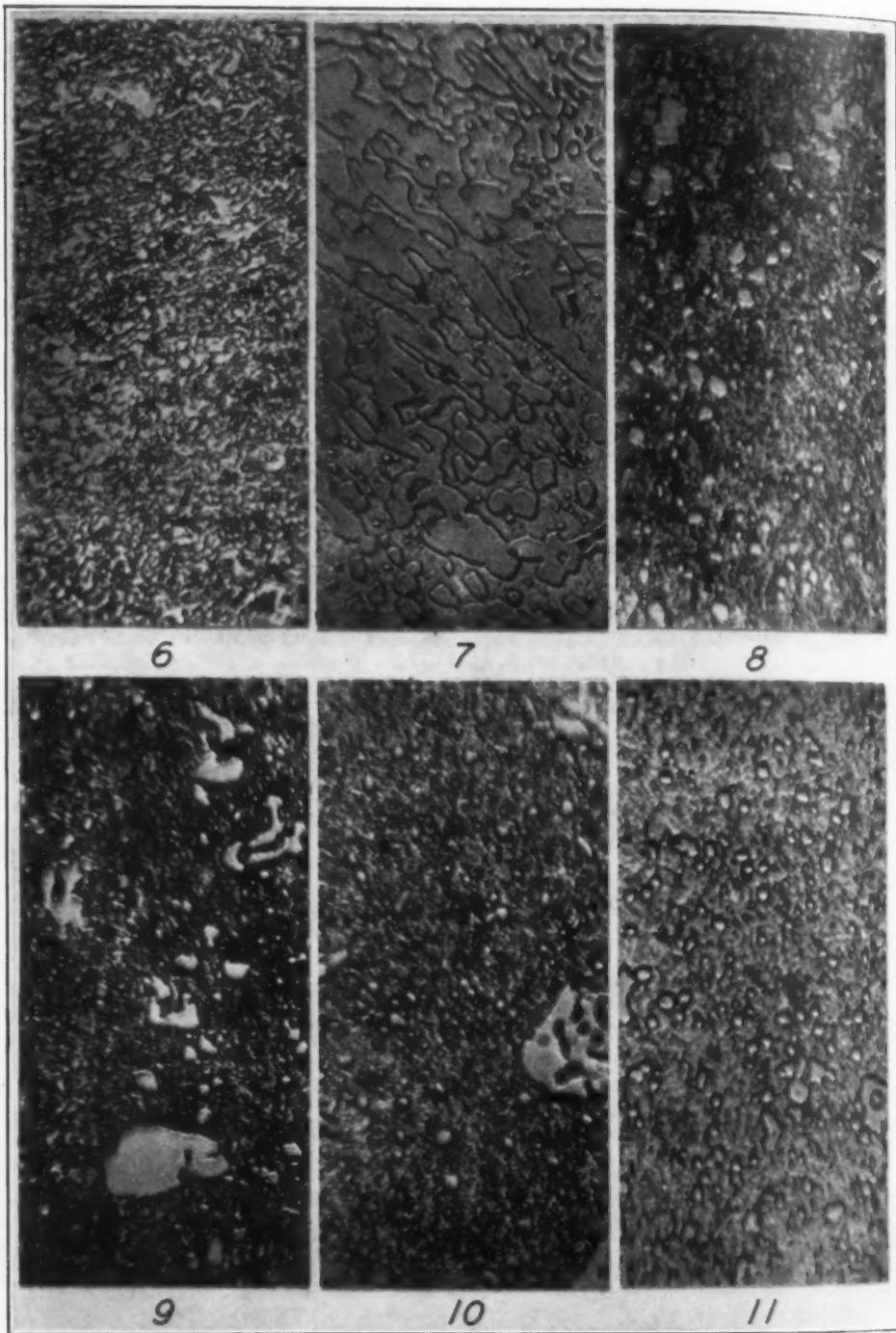
Microstructure Before Machining—The microstructures shown in Figs. 1 to 7 inclusive represent the structures of steels Nos. 1, 2, 4, 5, 6, 8 and 10 in either the annealed or the normalized condition. Steels 1, 2, 4, 6 and 8 are in the "as received" condition while steels 5 and 10 are in the annealed condition. These microstructures were found to be readily machinable.

Machining of Test Specimens—In the machining of the several kinds of test specimens little difficulty was encountered provided

Photomic
As Received.
As Received.
No. 4. As R
No. 5. Slow
Fig. 5—Steel



Photomicrographs of Steels as Received or in the Annealed Condition. Fig. 1—Steel No. 1. As Received. Etched with conc. HCl. Troostite and Carbide. 1000x. Fig. 2—Steel No. 2. As Received. Etched with Picric Acid. Austenite with Slip Lines. 1000x. Fig. 3—Steel No. 4. As Received. Etched with Picric Acid. Granular Pearlite. 1000x. Fig. 4—Steel No. 5. Slowly Cooled After Forging. Etched with Picric Acid. Granular Pearlite. 1000x. Fig. 5—Steel No. 6. As Received. Etched with Picric Acid. Lamellar Pearlite. 1000x.



Photomicrographs of Steels as Received or in the Annealed Condition. Fig. 6—Steel No. 8. As Received. Etched with Picric Acid. Granular Pearlite. 1000x. Fig. 7—Steel No. 10. Furnace-Cooled from 1470 degrees Fahr. After 30 Minutes at Temperature. Etched with Picric Acid. Granular Pearlite. 1000x.

Photomicrographs Showing the Effect of Quenching Temperature on the Austenitization of Steel No. 3 (Oil-quenched by Bain.) Fig. 8—Specimen No. 15 Quenched from 1500 degrees Fahr. Etched with Conc. HCl. Scleroscope 94.3. Troostite, Carbide. 1000x. Fig. 9—Specimen No. 16. Quenched from 1600 degrees Fahr. Etched with Conc. HCl. Scleroscope 94.7. Troostite, Carbide. 1000x. Fig. 10—Specimen No. 17. Quenched from 1700 degrees Fahr. Etched with Conc. HCl. Scleroscope 96.5. Troostite, Carbide, Martensite (?). Fig. 11—Specimen No. 18. Quenched from 1800 degrees Fahr. Etched with Conc. HCl. Scleroscope 89.4. Martensite, Carbide, Austenite. 1000x.

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Experimental Work and Results—The general plan of this investigation has been given in an earlier part of this thesis. The experimental work and results may be grouped under the heading of the decomposition of austenite: first, in normal quenching; second, when submerged in liquid oxygen; third, on reheating or drawing; and, fourth, under the influence of mechanical deformation.

The results of these tests have been supplemented and confirmed by X-ray analyses making use of the X-ray diffraction apparatus and the powder method of analysis as developed by Hull.

The details of this experimental work as well as the results obtained and the conclusion drawn are given in the following pages.

DECOMPOSITION OF AUSTENITE DURING QUENCHING

In order to retain austenite at room temperature so that its decomposition may be studied in coarse structures, it was found necessary to quench the steels from a high temperature. The photomicrographs shown in Figs. 8 to 14 inclusive show the effect of the quenching temperature on the retention of austenite in steel No. 3 for specimens about 0.38-inch square quenched in oil by E. C. Bain, but photographed by the writers. It should be noted that after quenching from 1800 degrees Fahr. (982 degrees Cent.) and above, the scleroscope hardness decreased rapidly and the steel became quite soft when quenched from 2100 degrees Fahr. (1150 degrees Cent.). Also, the structures obtained from the lower quenching temperatures, below 1900 degrees Fahr. (1038 degrees Cent.), have troostite with spheroidized carbide embedded. Above 1900 degrees Fahr. (1035 degrees Cent.) the specimens have the characteristic austenitic twins and are essentially nonmagnetic.

The quenching treatments for the various steels studied are given in Table III.

The last column in the table gives the numbers of the photomicrographs showing the microstructures produced as quenched. The quenching temperatures were measured with either a chromel-alumel or the noble metal thermocouple with a potentiometer indicator manufactured by the Leeds-Northrup Company of Phila-

Table III
Quenching Treatment of Specimens

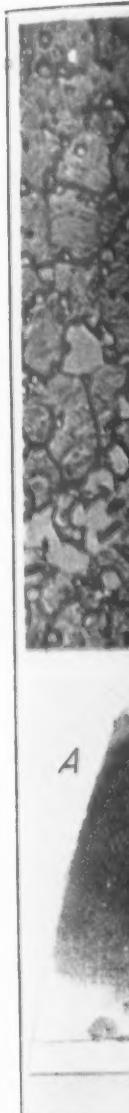
Steel No.	Sizes Treated in Inches	Quench. Temp., °C.	Time at Q. Temp., Min.	Heating Medium	Quenching Medium	Temp. of Q. Medium °C.	Numbers of Figs.
1	.36" diam.	1250	15	Carbon	5% NaOH + H ₂ O	—4	63
2	.44" x .69" sq.	1150	15	Carbon	5% NaOH + H ₂ O	—4	69-70
3	385" sq. Cyl. .35" d. x 3.5"	1200	15	Carbon	5% NaOH + H ₂ O	—4	79
	Ring No. 1, .678 o. d.	1150	15	Carbon	Oil	Room t.	115
	Ring No. 2, .5795" o. d.	1150	30	Carbon	Oil	Room t.	121
		1130	15	Carbon	Oil	Room t.	122
4	.49" sq.	1250	15	Carbon	5% NaOH	—4	86
5	.40" diam.	1250	15	Carbon	5% NaOH	—4	92, 93, 94
6	.45" diam. Cyl. .35" d. x 3.5"	1200	15	Carbon	5% NaOH	—4	97
	1" diam.	1150	15	Carbon	Oil	Room t.	119
		1150	15	Lead	Water	0°	
7	38" diam.	1350	15	Carbon	5% NaOH	—4	110
8	Cyl. .35" d. x 3.5"	1040	30	Carbon	Oil	Room t.	114
	Same	1040	30	Carbon	Oil	Room t.	
	Same	1150	15	Carbon	Oil	Room t.	
	Ring No. 3, .700" o. d.	1150	30	Carbon	Oil	Room t.	
	Ring No. 4, .700" o. d.	1250	30	Carbon	Oil	Room t.	123
	Cone 1" diam., 1½" Alt.	1100	30	Lead	Oil	Room t.	17
	Same	1100	30	Lead	Water	Room t.	20
	Cyl. 1" diam.	1260	30	Lead	Oil	Room t.	28
10	Cyl. .35" d. x 3.5"	1100	30	Carbon	Oil	Room t.	25
	Cone 1" diam., 1½" Alt.	1100	30	Lead	Oil	Room t.	23
	Same	1100	30	Lead	Water	Room t.	26
	Cyl. 1" diam.	1100	30	Lead	Water	Room t.	129

NOTE: All specimens continuously agitated in the quenching medium until they reached the temperature of the medium.

adelphia. Figs. 63, 69, 79, 86, 92, 97, 110,* and 28 show the maximum amount of austenite retained in steels Nos. 1 to 8 on quenching.

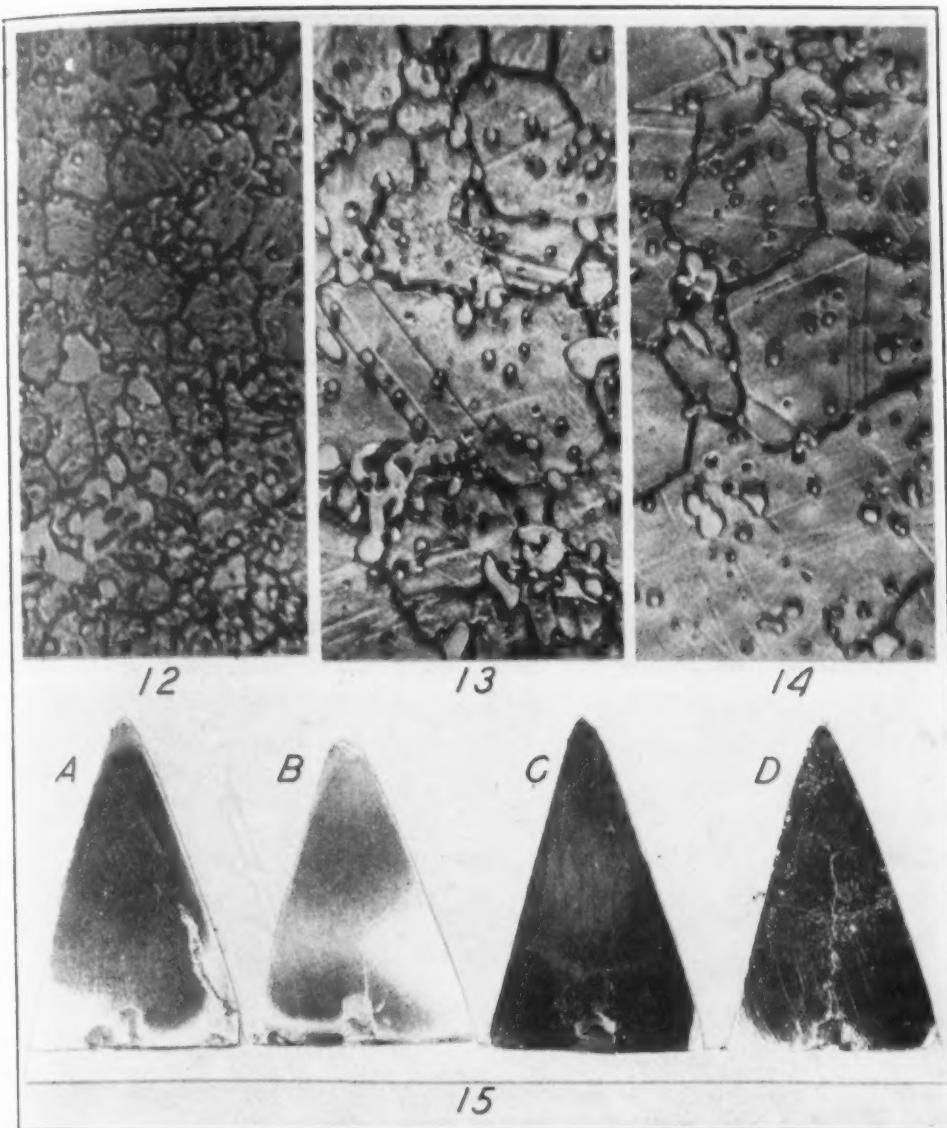
On examination of these photomicrographs it should be noted that the high alloy steels Nos. 1, 2, 3, 4, and 5 show nearly complete austenitization with the exception of some carbides in steels 3, 4 and 5. In steel No. 7 (Fig. 110) the structure is mostly martensitic. This term is used throughout this paper to represent the white needle "fer de lance" structure which forms

*Figs. 63, 69, 79, 86, 92, 97 and 110 are included in the paper on the decomposition of the austenitic structure on drawing, which will appear later.



Photomicrographs of Steel No. 44.9 at 44.9 degrees Fahrenheit with Cone. Specimen No. 44.9. Carbide. 1000x. Tensile Strength at 1832 Degrees Fahrenheit.

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Photomicrographs Showing the Effect of Quenching Temperature on the Austenitization of Steel No. 3 (Oil-quenched by Bain.) Fig. 12—Specimen No. 19. Quenched from 1900 degrees Fahr. Etched with Conc. HCl. Scleroscope 55.0. Martensite Needles Austenite Carbide. 1000x. Fig. 13—Specimen No. 20. Quenched from 2000 degrees Fahr. Etched with Conc. HCl. Scleroscope 47.4. Carbide Austenite with Twins. 1000x. Fig. 14—Specimen No. 21. Quenched from 2100 degrees Fahr. Etched with Conc. HCl. Scleroscope 44.9. Carbide Austenite with Twins. 1000x. Fig. 15—Photomacrographs of Polished Sections of Test Cones (1 inch Diameter Base—Altitude 1½ inches) Along Altitudes to Show Cracks Produced in Quenching. All Specimens Quenched from Lead Baths After 30 Minutes at 1832 Degrees Fahr. (1100 degrees Cent.) Actual Size.

from the austenite when cooled to room temperature and below. In steel No. 8 the martensite is much more clearly defined and coarser (Fig. 28). In steel No. 10 both martensite and troostite occurred in the groundmass with many needles

of carbide and small amounts of graphite. This condition was particularly true at the center of the specimen. Closer to the edge of the specimen a coarser martensite occurred in some areas. The martensite areas were somewhat more conspicuous after drawing, in which condition they etched dark. It seems invariably the case that one finds a very fine acicular martensite at the edges which becomes coarser and less in amount as the centers of the sections are approached.

EFFECT OF STRESS PRODUCED BY QUENCHING ON THE DECOMPOSITION OF AUSTENITE

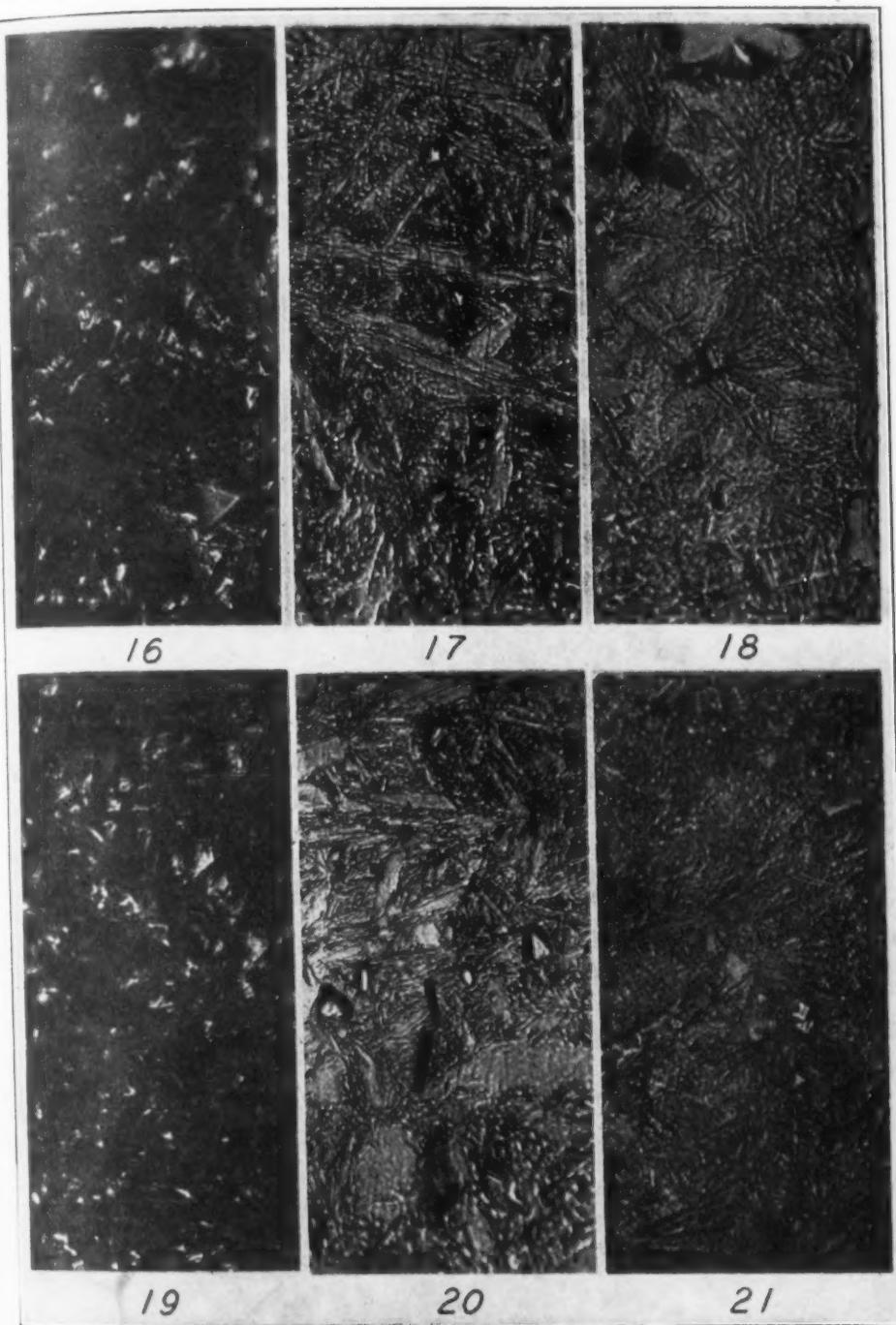
In order to show the effect of quenching stress on the formation of martensite from austenite for various cross-sections a cone test piece was also used, along with cylindrical specimens of 1 inch and 0.35 inch in diameter. Steels Nos. 8 and 10 were selected for this experiment on account of the strong tendency they showed for martensitic retention. Cones were machined having a base diameter of 1 inch with an altitude of $1\frac{1}{2}$ inches. The centers of the bases were tapped and a small $\frac{1}{8}$ -inch bolt was screwed into each base to facilitate quenching from a lead bath. Fig. 15 shows sections through the altitudes of these cones after quenching. Most of the cracks which occurred during the late stage of quenching start from the inside and indicate that after quenching there was a reversal of stress which left the outside under compression and the inside in tension.

Figs. 17 and 20 show that slightly more austenite was retained in the middle of the cones of steel No. 8 than was retained on the base edge (Figs. 18 and 21). The apexes, Figs. 16 and 19, were unfortunately tempered to a troostite with the grinding wheel in cutting the sections, although a considerable amount of water was used for cooling the work.

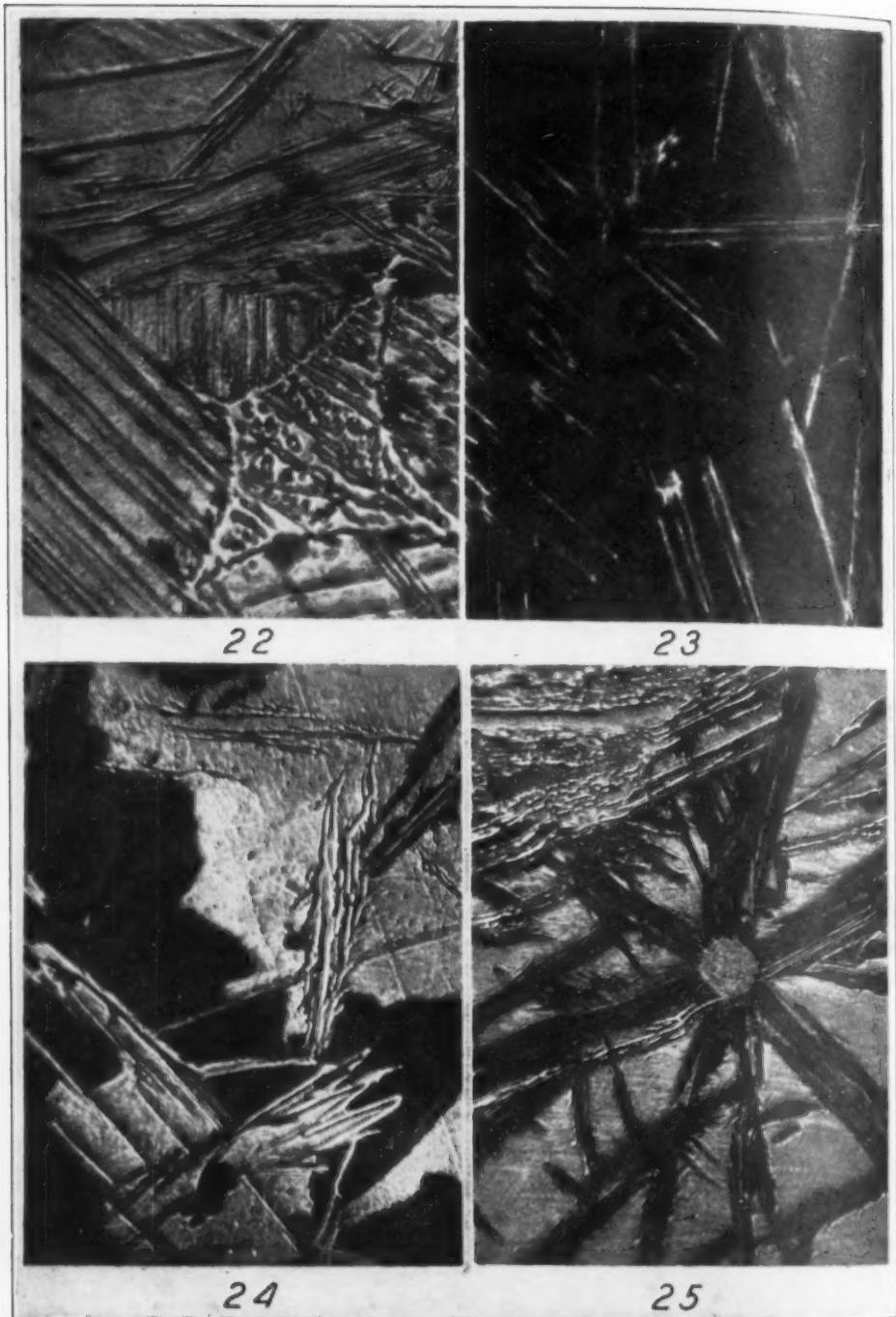
Water and oil-quenched cylinders of 1-inch diameter and 1-inch high of this steel (No. 8) showed only slightly more austenite at the center than on the edges (Figs. 28, 29, 30, and 31). However, when a 0.36-inch diameter bar of steel No. 8 was quenched in oil from 2100 degrees Fahr. (1150 degrees Cent.) it was found that the outside edge of the bar developed a very fine acicular martensite which probably contains some austenite between the needles, while the center of the bar showed a much coarser struc-

Photomicrograph showing the effect of stress on the decomposition of austenite. The image shows a dark, granular structure with some bright, elongated features, likely representing austenite and martensite respectively, as described in the text.

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Photomicrographs Showing Tests on Cones of Steel No. 8, Water-quenched after 30 Minutes at 1100 Degrees Cent. Fig. 16—Apex. Etched with Picric Acid. Troostite—Austenite. 1000x. Fig. 17—Middle on Altitude. Etched with Picric Acid. Martensite—Austenite. 1000x. Fig. 18—Edge on Base. Etched with Picric Acid. Mostly Martensite with Austenite Groundmass and Carbide. 1000x. Fig. 19—Apex. Etched with Picric Acid. Troostite Carbide. 1000x. Fig. 20—Middle on Altitude. Etched with Picric Acid. Martensite Austenite Carbide. 1000x. Fig. 21—Edge on Base. Etched with Picric Acid. Mostly Martensite Some Austenite Carbide. 1000x.



Photomicrographs Showing Tests on Cones of Steel No. 10, Oil-quenched After 30 Minutes at 1100 degrees Cent. Fig. 22—Apex. Etched with Picric Acid. Austenite Carbide Troostite. 1000x. Fig. 23—Middle on Altitude. Etched with Picric Acid. Troostite Carbide. 1000x. Fig. 24—Edge on Base. Etched with Picric Acid. Austenite Troostite Carbide. 1000x. Fig. 25—Apex. Etched with Picric Acid. Austenite Troostite Carbide. 1000x.

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RESULTS

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Photomicrographs of these structures will appear later as Figs. 114 and 115. On comparing the centers of carbon steel No. 10 on oil and on water quenching, it will be found that the centers (Figs. 23 and 26) show considerable troostite and thin carbide needles with a groundmass almost wholly troostitic in Fig. 23. The apexes (Figs. 22 and 25) and the bases (Figs. 24 and 27) show that considerable austenite was retained on the outside edge. A higher quenching temperature and a longer time at temperature would have been much more desirable in eliminating the rather massive carbide areas in some parts of these sections.

On oil quenching a 0.35-inch diameter bar of steel No. 10 it was found that, similarly to the experiments with steel No. 8, slightly more martensite occurred on the outside edge than in the center. Water quenching a 0.35-inch diameter cylinder of this steel produced quite a marked outside rim of martensite which had a depth of about 0.5 millimeters. This martensitic zone was of greater depth than that obtained with steel No. 8 in a similar experiment.

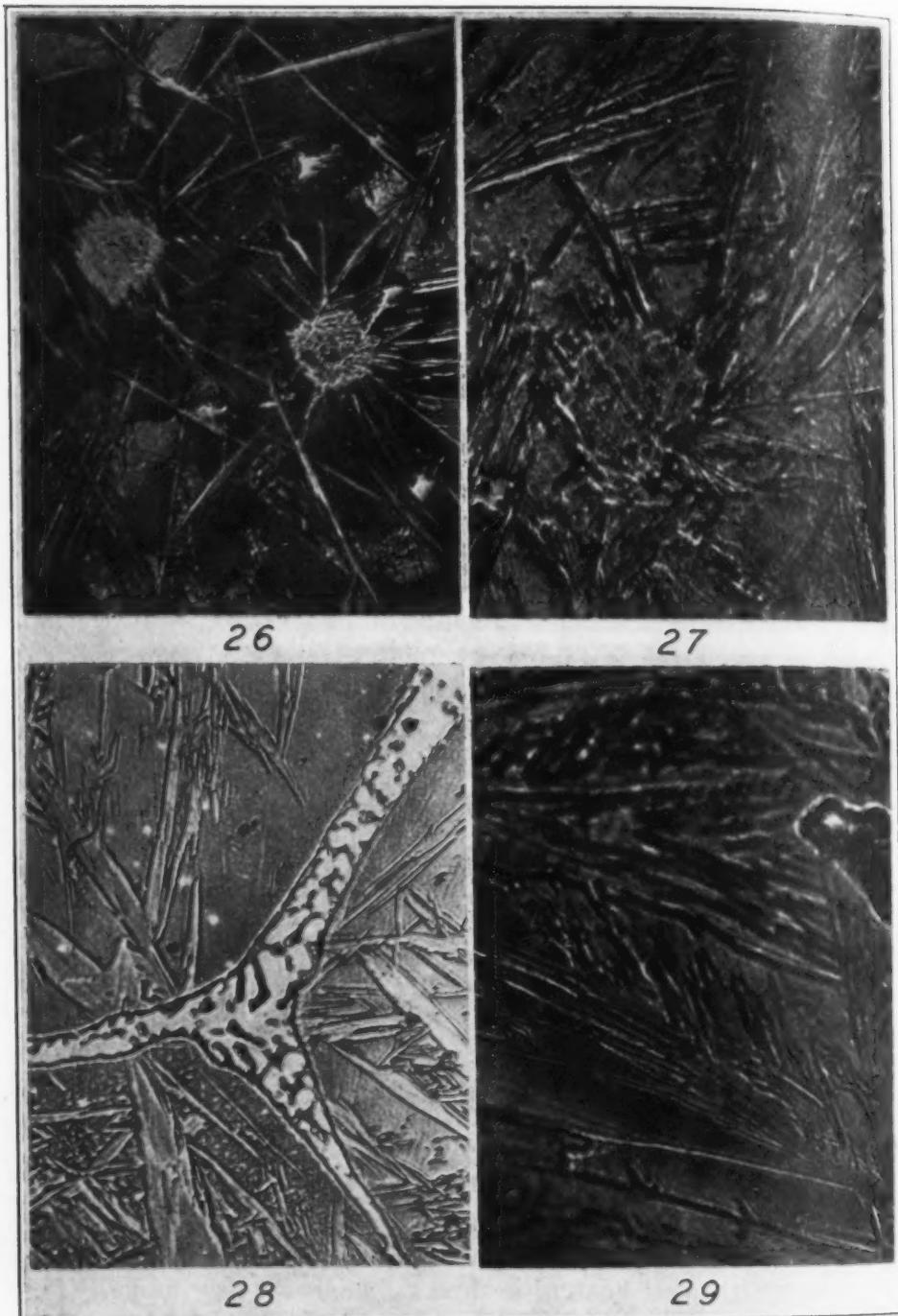
On water quenching steel No. 7 from about 2462 degrees Fahr. (1350 degrees Cent.) in a 5 per cent solution of NaOH in water at 24 degrees Fahr. (—4 degrees Cent.), it was found that patches of austenite, similar to Fig. 110 were retained only at the center while the edges had the typical fine acicular martensite with a groundmass that was probably austenite but too fine to be definitely identified. This martensite is typical of what is produced in industrial heat treating.

On water quenching steel No. 3 martensitic needles are commonly found near the edges of the pieces while the microscope reveals only austenite and carbide in the center.

On water quenching and on oil quenching steel No. 9 (blades 1/32 inch thick and 1/2 inch wide) from temperatures under its melting point, a fine type of "fer de lance" structure was obtained throughout with the austenitic areas hardly large enough for identification.

RESULTS OF TESTS ON THE DECOMPOSITION OF AUSTENITE ON QUENCHING

The results obtained from the tests described indicate that:



Photomicrographs Showing Tests on Cones of Steel No. 10. Oil-quenched After 30 Minutes at 2010 degrees Fahr. (1100 degrees Cent.) Fig. 26—Middle on Altitude. Etched with Picric Acid. Austenite Troostite Carbide. 1000x. Fig. 27—Edge near Base. Etched with Picric Acid. Austenite Carbide. 1000x.

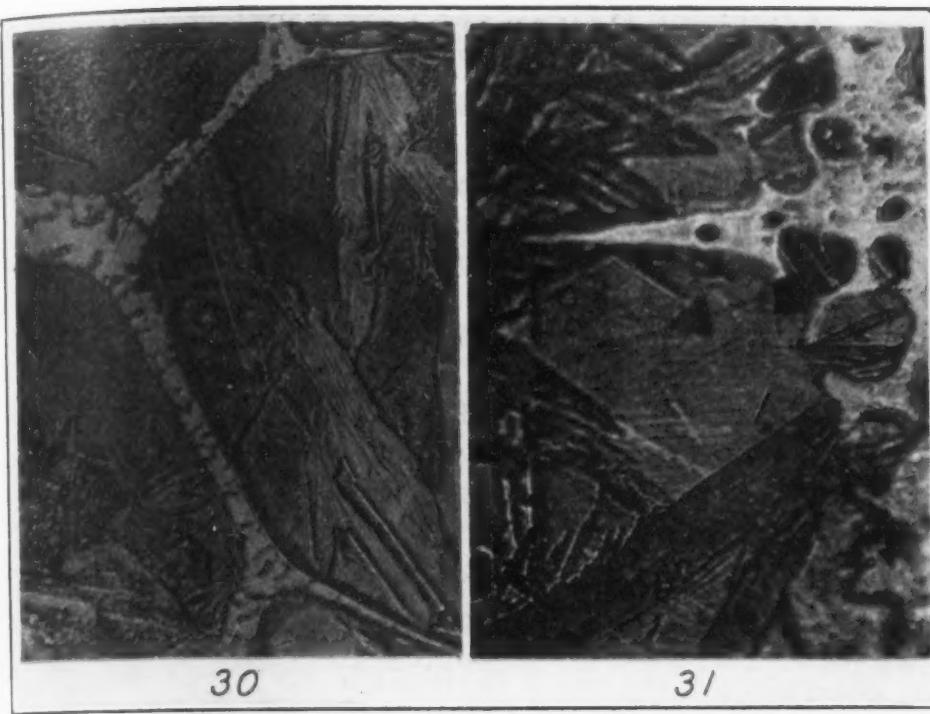
Photomicrographs Showing Effect of Quenching Stresses on the Production of Martensite on Cylindrical Bars of 1 Inch Diameter and 1 Inch High. Steel No. 8. Quenched after 30 Minutes from 2300 degrees Fahr. (1260 degrees Cent.) in Oil. Fig. 28—Center of Oil-quenched Specimen. Etched with Picric Acid. Austenite Martensite Carbide. 1000x. Fig. 29—Outer Edge of Oil-quenched Specimen. Etched with Picric Acid. Austenite Martensite. 1000x.

Photomicrographs on Cylindrical Bars of 1 Inch Diameter and 1 Inch High. Steel No. 8. Quenched after 30 Minutes from 2300 degrees Fahr. (1260 degrees Cent.) in Oil. Fig. 28—Center of Oil-quenched Specimen. Etched with Picric Acid. Austenite Martensite Carbide. 1000x. Fig. 29—Outer Edge of Oil-quenched Specimen. Etched with Picric Acid. Austenite Martensite. 1000x.

a. In order to obtain the best mechanical properties, the quenching temperature should be as high as possible, provided that the temperature is not so high that the steels are not fully austenitized. The steels should be quenched rapidly. The following treatments are recommended: 1. Oil-quenching of 1010 steel at 1100 degrees Cent. 2. Water-quenching of 1010, 1020, and 1030 steels at 1100 degrees Cent. 3. Air-quenching of 1010, 1020, and 1030 steels at 1100 degrees Cent.

b. A quenching temperature of 1100 degrees Cent. will produce more martensite than a lower temperature, but the difference in the amount of martensite produced will be small. The amount of martensite produced will be greater at a higher quenching temperature, but the difference in the amount of martensite produced will be small. The amount of martensite produced will be greater at a higher quenching temperature, but the difference in the amount of martensite produced will be small.

c. The quenching temperature should be as high as possible, provided that the temperature is not so high that the steels are not fully austenitized. The steels should be quenched rapidly. The following treatments are recommended: 1. Oil-quenching of 1010 steel at 1100 degrees Cent. 2. Water-quenching of 1010, 1020, and 1030 steels at 1100 degrees Cent. 3. Air-quenching of 1010, 1020, and 1030 steels at 1100 degrees Cent.



Photomicrographs Showing Effect of Quenching Stresses on the Production of Martensite on Cylindrical Bars of 1 Inch Diameter and 1 Inch High. Steel No. 8. Quenched after 30 Minutes from 2300 degrees Fahr. (1260 degrees Cent.) in Oil. Fig. 30—Center of Water-quenched Specimen. Etched with Picric Acid. Austenite Martensite Carbide. 1000x. Fig. 31—Outer Edge of Water-quenched Specimen. Etched with Picric Acid. Austenite Martensite Needles (Tempered). 1000x.

a. In order to obtain a large amount of austenite at room temperature, a high carbon steel and preferably an alloy steel should be used. The austenitic retention at room temperature of the steels studied is in the following decreasing order for the sizes treated: Manganese steel No. 2, Nickel steel No. 5, Carbon-chromium steel No. 3 and Cobalt-chromium steel No. 1, High Speed steel No. 4, Tungsten steel No. 8 and High Carbon steel No. 10, Chromium Magnet steel No. 7, and High Carbon steel No. 6.

b. An oil quench from a high initial temperature will produce more austenite than a more drastic quench, such as water, from the same temperature. Oil quenching must produce a lower tensile stress in the outer zone than water quenching, otherwise more cracking would take place from oil quenching. This is probably due to the lower temperature difference between the outside zone and the center during the quenching.

c. The more drastic quenching of the smaller sizes (about $\frac{3}{8}$ -inch diameter) produces more martensite at the edges of the

pieces which is probably due to the greater difference in temperature existing between the outside and the center which should produce a higher tensional stress. This favors martensite formation because of the increased volume when martensite forms. During the first stage of quenching the outside of the section must be in tension which will produce a compression on the inside and tend to retain the austenite by preventing its expansion to martensite. However, it is believed by the writers that the absence of tensional stress is of more importance in the retention of austenite at room temperature than is the compressive stress.

d. In the case of quenched sections which are martensitic throughout, the following mechanism is suggested: In the first part of the cooling operation the surface must be in tension and the core in compression, but as the cooling continues the tension zone progresses inward. As the outer zone produces martensite of a greater specific volume than the austenitic core it should lower the tension and gradually produce compression in the outer zone. The temperature of the core at the time the case changes to martensite on quenching must be considerably higher and as the core cools to ordinary temperature there is a shrinkage due to the normal decrease in volume with decrease in temperature. This must play an important part in producing tension in the core. At this time the outer compressive zone must be balanced by an equal tensional zone in the interior of the specimen which will promote the formation of martensite. This explanation is in agreement with the stress distribution studies of several investigators.

e. If either large or small sections are quenched from a high temperature they will contain more austenite than if quenched from normal quenching temperatures. The following explanation for this phenomenon is offered: At high temperatures larger austenite grains are produced. It is considered that the larger austenite grains will have a greater stability than the smaller ones, and it has been observed that the slip lines or needles produced in a coarse-grained structure are longer and wider which results in a coarser martensitic structure and gives the appearance of a smaller amount of martensite. The stability of the large grains produced at high temperatures is further increased in steels containing an excess of carbides by the larger amount of carbon taken into solution in the austenite.

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WEAR RESISTANCE OF CARBURIZED STEEL VERSUS CAST HIGH MANGANESE STEEL

BY W. J. MERTEN

Abstract

The experiments described were made to determine comparative wear resistance of 14 per cent manganese cast steel and case hardened steel when subjected to relatively high pressure with movements free from shock or pounding. Plastic flow under heavy pressure during a gliding motion is apparently the cause of considerable abrasion on manganese steel while it has decidedly less influence upon case hardened steels.

INTRODUCTION

THE ramifications presenting themselves upon the interpretation of results obtained in testing the wear resistance of hard surfaces lead to a perplexity defying generalization as to which set of conditions are most favorable for satisfactory performance. Conditions of actual service are so complex that results obtained from one set of specific conditions do not obtain in another. However, it may be stated that the fundamental requirements for wear resistance as applied to metals are—a low coefficient of friction between the metals, which naturally depends upon the surface conditions or relative wearing qualities of the contacting metals.

Results here obtained are probably duplicates of some published by others, however, a review from another perspective or angle certainly should prove of interest and throw additional light upon the still chaotic and meagerly explored field of wear resistance of hard austenitic manganese steel as compared to hardened martensitic carburized steel surfaces.

Purpose of Experiments

The experiments were conducted to ascertain the relative wear resistance qualities of flexible spring seats and pads when made from carburized steel and also 14 per cent manganese steel.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, W. J. Merten, is metallurgical engineer with the Westinghouse Electric and Manufacturing Co., East Pittsburgh.

METHOD OF TESTING

Apparatus

A quill drive spring unit assembly shown in Fig. 1 suggested the method of testing, which was adopted and which most closely resembled the actual service conditions. This spring unit was connected to a belt-driven crankshaft and clamped between

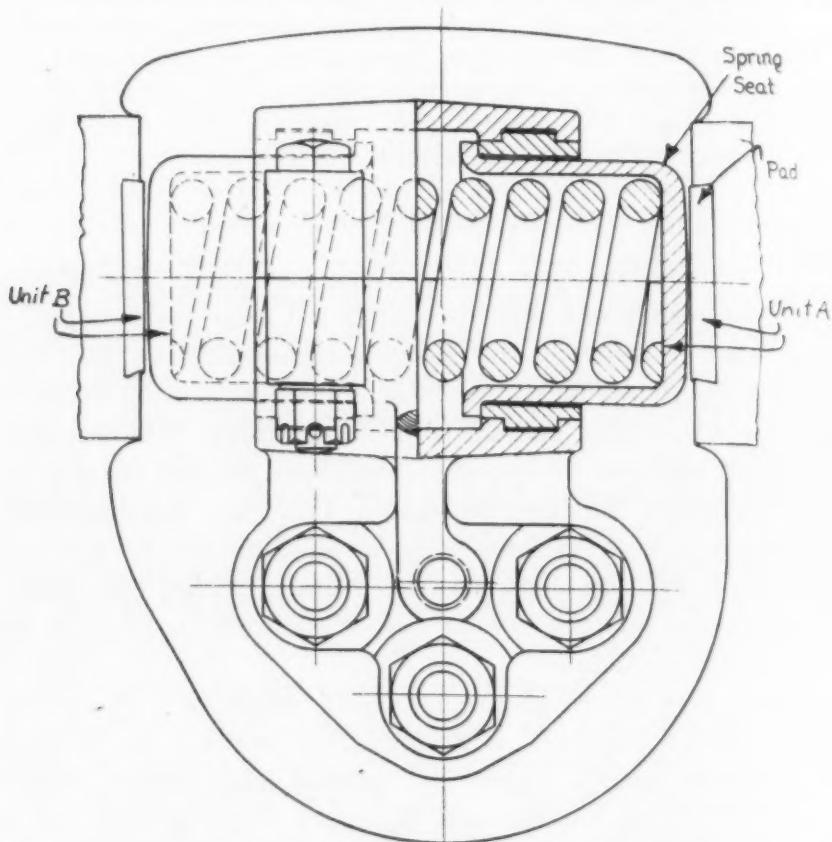


Fig. 1—Quill Drive Spring Unit Assembly.

an adjustable stationary upright member, to which were welded the wearing pads. This arrangement provided the essential requirements for testing of quality of wear resistance, namely, sliding motion of a definite rate of speed and pressure of selected and measured magnitude. Fig. 2 is a photograph of the apparatus and shows a motor-driven crankshaft of 1-inch throw of crank (giving a total displacement of 2 inches forward and 2 inches backward), to which is fastened a sliding frame carrying the spring unit which travels between the wearing pads fastened

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to the adjustable stationary steel members secured to pedestals, which in turn are bolted to the bedplate.

The pressure is regulated by adjusting the stationary members so as to compress the spring a definite amount, the magni-

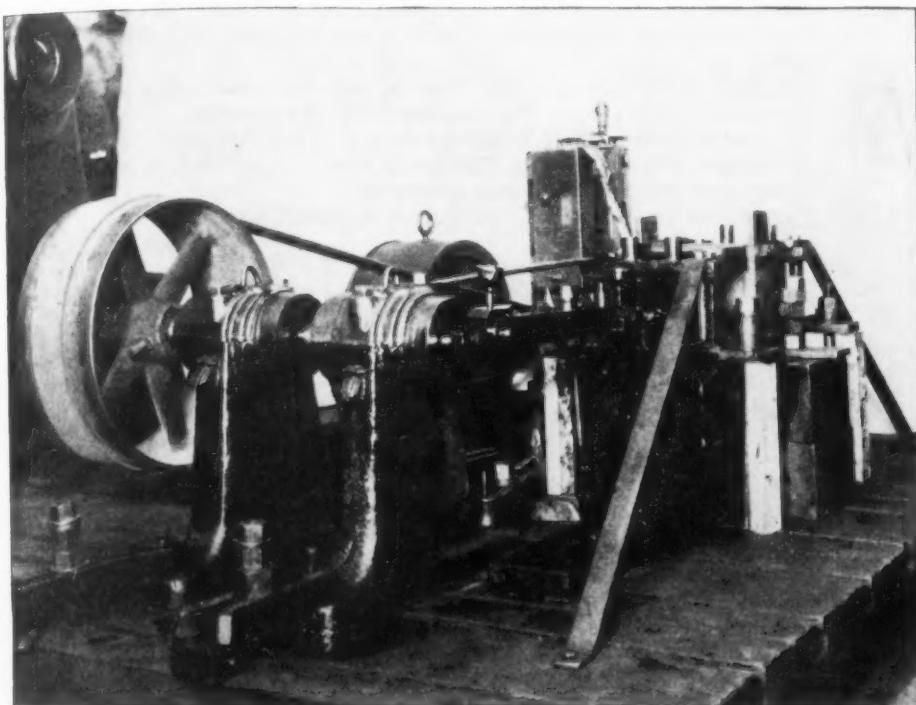


Fig. 2—Photograph of Apparatus Used in Testing the Wear Resistance of Spring Units.

tude of which was obtained from the spring characteristic or calibration curves (Figs. 3 and 4) carefully determined before application and rechecked after each test run to determine any change.

The design and assembly made it possible to make a direct comparison between the wearing qualities of case hardened carbon steel and 14 per cent manganese steel by using one seat and pad of carburized steel and the other seat and pad of manganese steel, pressure, speed, and all other conditions being identical.

The following is a conversion of the speed in revolutions per minute into feet of travel per hour in order to render tabulated data more intelligible.

130 revolutions per minute	= 2600 feet per hour
140 revolutions per minute	= 2800 feet per hour
150 revolutions per minute	= 3000 feet per hour

MATERIALS TESTED

The materials tested were cast 14 per cent manganese steel and carefully carburized plain carbon steels. The chemistry and physical condition is as follows:—

1. Case Hardened Spring Seat made from 0.35 per cent carbon B. O. H. hot-rolled steel
2. Case Hardened Wearing Pad made from 0.15 per cent carbon B. O. H. steel
3. Manganese Steel Seat made from 14 per cent manganese steel as cast
- 3a. Manganese Steel Seat Water-Quenched (Austenitic)
- 3b. Manganese Steel Seat Water-Quenched and Tempered (Martensitic)
4. Manganese Steel Wearing Pad made from 14 per cent manganese steel
- 4a. Manganese Steel Pad Water-Quenched
- 4b. Manganese Steel Pad Water-Quenched and Tempered

TEST RUN No. 1

The Assembly for

Unit A contained Material 2+3 Unit B contained Material 1+2

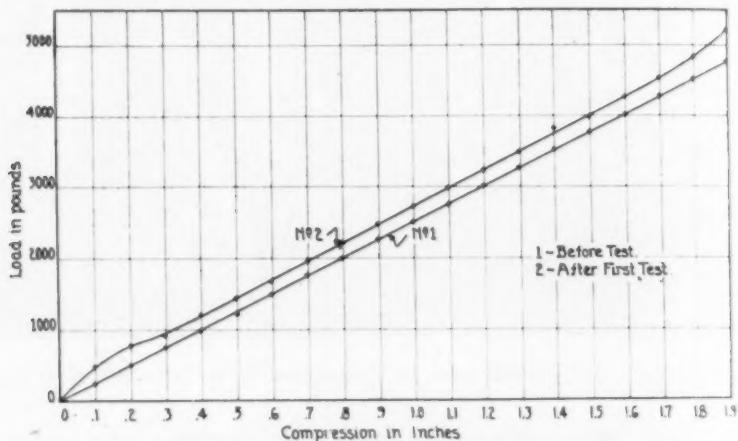


Fig. 3—Load-Compression Curves on Wearing Test Spring.

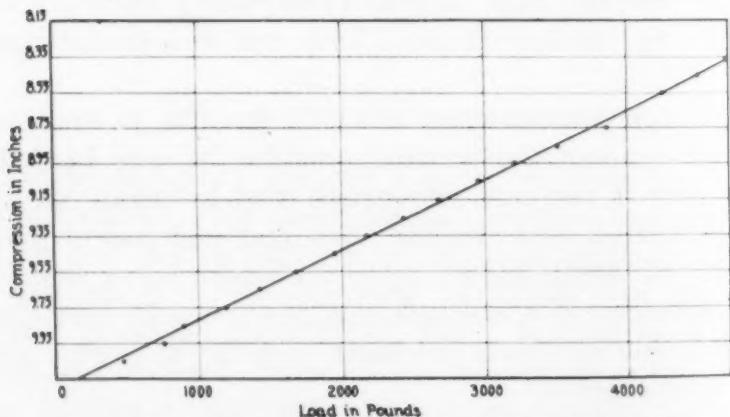


Fig. 4—Load-Compression Curves on Wearing Test Spring.

During the first two days of testing, lubrication of surfaces

Table I
Wearing Qualities of Carburized Steel vs. Manganese Steel (14% Mn.)

Days Total	Unit A	Unit B	Carburized Pad Against Manganese Seat	
			Carburized Steel Seat	Against Carburized Seat

Table I
Wearing Qualities of Carburized Steel vs. Manganese Steel (14% Mn.)

Hours of Test	Run	R. P. M.	Total Hours	Pressure in Pounds	Thickness, Wear, Inches Per Run	Total Wear	Thickness, Wear, Inches Per Run	Total Wear	Thickness, Wear, Inches Per Run	Total Wear	Thickness, Wear, Inches Per Run	Total Wear	Unit A		Unit B		Days Total
													Manganese Steel Seat	Carburized Pad Against Manganese Seat	Carburized Steel Seat	Against Carburized Seat	
6 1/4	130	9	2200	.629	... .001	1.540	... .007	... .587	... .004	... .583	... .004	... .583	... .004	... .515	... .008	... .008	280,800
4	150	... .	2200	.628	... .001	1.533	... .007	... .583	... .004	... .583	... .004	... .583	... .004	... .507	... .008	... .008	195,000
9 1/4	150	13 1/4	1535	.609	... .009	1.533	... .008	... .015	... .022	... .022	... .022	... .022	... .026	... .0504	... .0504	... .0504	144,000
6 1/4	150	19 1/2	1535	.600	... .	1.525	... .010	... .561	... .022	... .022	... .022	... .022	... .026	... .500	... .003	... .011	323,000
2	150	21 1/2	2200	... .	... .	1.524	... .001	... .016	... .	... .	... .	... .	... .	... .500	... .004	... .015	225,000
8	130	29 1/2	2159	... .	... .	1.523	... .001	... .017	... .	... .	... .	... .	... .	... .497	... .003	... .018	72,000
9	130	38 1/2	2098	.564	... .036	1.520	... .003	... .020	... .520	... .041	... .041	... .041	... .067	... .492	... .004	... .022	249,600
6	130	43 1/2	2037	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	280,800
9 1/2	130	53	1976	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	156,000
9	130	62	1894	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	296,400
4	130	66	1832	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	280,800
9 1/4	130	75 1/4	1771	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	124,800
6 3/4	130	82	1710	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	288,600
7 1/2	130	89 1/2	1649	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	210,600
8	130	97 1/2	1587	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	234,000
8	140	105 1/2	1526	... .	... .	1.514	... .006	... .026	... .	... .	... .	... .	... .	... .488	... .004	... .026	249,600
3	130	108 1/2	1465	... .	... .	1.505	... .009	... .036	... .	... .	... .	... .	... .	... .475	... .013	... .013	268,000
7 1/2	130	116	1404	... .	... .	1.480	... .025	... .060	... .	... .	... .	... .	... .	... .475	... .039	... .039	93,000
23	130	139	1343	.470	.094	1.40	.140	.094	.475	.045	.112	.1465	.045	.112	.049	.049	717,600
						Total travel in feet, 411,183.								Total travel in miles, 77.9.			Total, 4,934,200

Table II
Wearing Qualities of Carburized Steel vs. Manganese Steel (14% Mn.)

Hrs. of Test	Total Hours	R. P. M.	Comp. in Lbs.	Manganese Seat	Carburized Seat	Manganese Carburized Pad	Mang. Seat	Total Wear in Inches	Weight in Grams			Weight in Grams	
									Carb. Pad	Mang. Pad	Carburized Pad		
66	66	130	1600	.018"	... .005"	... .075"	... .005"	... .	Not Determined	Not Determined	Not Determined	3493.1
33	99	130	1700	.032"	... .006"	... .100"	... .006"	... .	Not Determined	Not Determined	Not Determined	3760.6
67	166	130	1700	.066"	... .002"	... .117"	... .064"	.64.8	34.7	34.7	34.7	3724.9
77	243	130	1750	.106"	Irregular Flow	... .	129.7	53.8	53.8	53.8	53.8	3363.4
									Flowed	Flowed	Flowed		3706.8

was tried; it was soon found, however, that it was impractical to obtain uniform lubrication, and certainly this would not be attempted in service. All later runs were made with dry surfaces rubbing against each other.

Table I shows detailed data of the test including pressure, speed, time periods between measurements of wear and results; it also shows that both pads in this instance were of case hardened steel. In Fig. 5 the results are plotted and apparently a greater

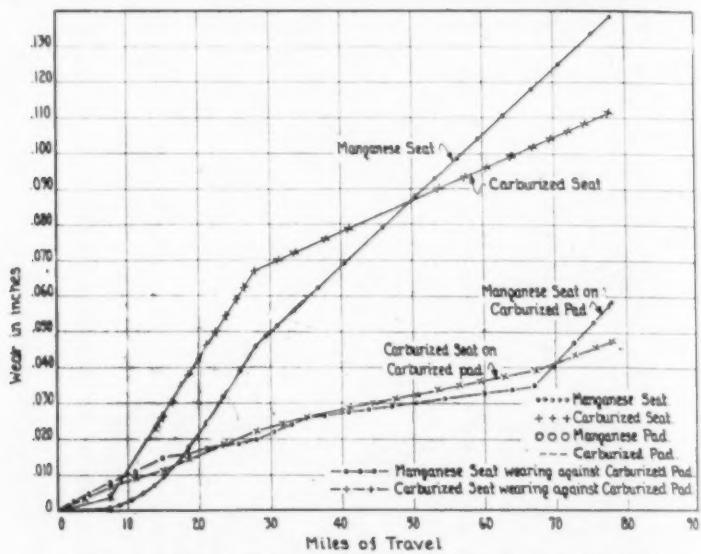


Fig. 5—Curves Indicating Flow and Wear of Steel Parts.

regularity of wear and more consistent abrasive resistance results on case hardened seats and pad, and it is very likely that the irregular plastic flow and wear of the manganese seat has influenced the wear resistance of the case hardened pad. Also, it will be noted that the wear of the pads was measured and checked oftener than the spring seats, their position in the apparatus being favorable to the making of such measurements without dismantling the apparatus.

TEST RUN No. 2

The Assembly for

Unit A was Material 3+4 and for Unit B was Material 1+2

In Run No. 2 the assembly of seats and pads was arranged as originally planned and previously indicated; a case hardened spring seat wearing on a case hardened pad on one end of the spring and a manganese steel seat wearing against a manganese

steel pad results of of the sea uniformly spring sea hardened decrease because it the metal uncertain

the case ha to determin thickness o ever, on a determined tests due t loss by wea ness. The sistent and while confi surprising a

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steel pad on the other end of the spring. Table II gives the results of this run and Fig. 6 shows curves plotted from the wear of the seats as determined by loss of weight, and illustrates the uniformly progressive loss by abrasion of the manganese steel spring seat. This is more than twice as great as the wear of the case hardened steel spring seat. The change from measurement of decrease of thickness of seat to that of loss of weight was made because it was found after 66 hours of run that the flow of the metal was erratic and measurements of wear were difficult and uncertain and after another 33 hours' run the flow of metal of

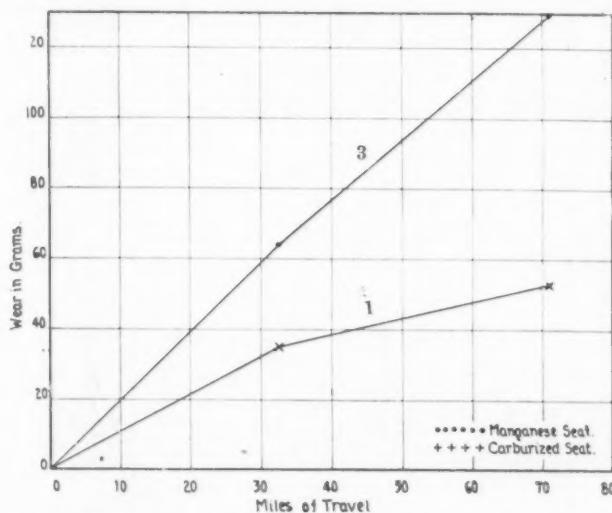


Fig. 6—Curves Indicating Flow and Wear of Steel Parts.

the case hardened seat became very pronounced, so it was decided to determine the wear by loss in weight and measure decrease of thickness of seats as a check only. The wear on the pads, however, on account of being welded to the stands, could not be determined by weighing without considerably complicating the tests due to the difficulty of dismantling and reassembling and loss by wear has been obtained from direct measurement of thickness. The surface of the pads being flat, the wear was more consistent and uniform than on the curved seat surfaces. The results, while confirming those obtained in the previous test, were rather surprising and disappointing and unfavorable for manganese steel.

It may be contended that the higher wear loss of the case hardened plate offsets the gain in the seat, however, it is quite evident from a study of the drive assembly that it is more desirable

for the w

Table III
Wearing Qualities of Carburized Steel vs. Manganese Steel (14% Mn.)

Total Hours of Exp. Run	Hours Test Between Checks	R. P. M.	Compression Load in Pounds	Weight of Manganese Seat Grams	Wear in Grams of Manganese Seat	Carburized Seat	Carburized Seat	Total Wear of Carburized Seat
0	0	0	0	3666.3	0	3825.7	0	0
81	81	130	1600	3593.7	72.6	3801.7	24.0	24.0
143	62	130	1600	3519.0	75.7	3781.3	20.4	44.4

Table IV

0	0	0	1700	3692.5	0	77.0	0	3831.7	0
130	130	130	3615.5	3615.5	77.0	3790.8	40.9	40.9	40.9

Table V

Total Hours of Run	R. P. M.	Compression Load	Weight in Grams Manganese Seat	Weight in Grams Carburized Seat	Wear in Grams Manganese Seat	Thickness of Manganese Pad	Carburized Pad	Wear in Inches of Manganese Pad	Carburized Pad
0	0	0	3703.5	3755.5	0	41.5	1.270"	1.274"	0
80	130	1700	3631.6	3714.0	71.9	41.5	1.252"	1.256"	.018"

BRINELL HARDNESS NUMBERS

Manganese Seat, 330.0, Manganese Pad, 351.0,
Carburized Seat, 650.0, Carburized Pad, 450.0,
Wearing Qualities of Carburized Steel Versus Manganese Steel (14 Per Cent Mn.)

in cold water data and results of the pads on miles of

Unit A

The next
"as cast", opened seat an

for the wear to take place on the pad as this is easier to replace.

TEST RUN No. 3

The Assembly was

*Unit A—Material 3a+4a Unit B—Material 1+2
quenched (austentic)*

The unfavorable results on manganese steel seats found in Run 2 suggest a reheat treatment of the seats and pads and quench

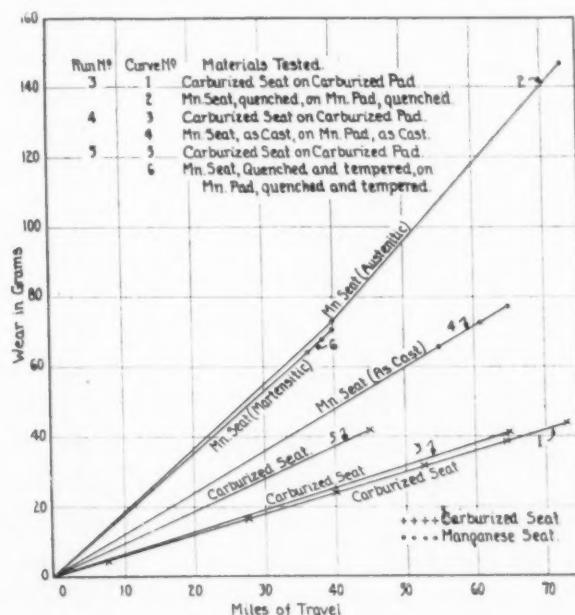


Fig. 7—Curves Indicating Flow and Wear of Steel Parts.

in cold water. The test was then repeated. Table III gives the data and result of this test; it will be noted that the wear-loss of the pads has been omitted. In Fig. 7 these results are plotted on miles of travel and gram-wear co-ordinates.

TEST RUN No. 4

The Assembly was

Unit A—Materials 3+4 and Unit B—Materials 1+2 as cast

The next run was made with a manganese steel seat and pad "as cast", omitting any treatment, and compared with case hardened seat and pad. The intermediate check measurements were

1927

omitted and the final loss in weight by wear only determined. Table IV gives detailed data and results, and Fig. 7 shows the plot. The case hardened seat checks the previous results perfectly, while the "as cast" manganese steel seat has a considerably smaller loss due to wear than the toughened manganese steel seat.

TEST RUN No. 5

The Assembly was

Unit A—Materials 3b+4b Unit B—Materials 1+2

The improved results of Test Run No. 2 and Run No. 4 (Curve 4, Fig. 7) on a "as cast" manganese steel suggested a treatment of the manganese steel seats and pads to produce a martensitic structure for increasing its wear resistance. A manganese steel seat and pad were consequently heated to 1925 degrees Fahr. (1050 degrees Cent.) and quenched from this temperature in cold water and reheated and held at a temperature of 1070 degrees Fahr. (575 degrees Cent.) for 24 hours and put under test as before. Table V gives the detailed data and results of test. These results of weight loss by wear plotted against mileage, as illustrated by curves in Fig. 7, show that no improvement has been brought about in service performance under conditions such as are peculiar to locomotive flexible drives by reheating for tempering an austenitic manganese steel. It should also be observed that the wear on the pads is practically the same and that the critical wearing members of the apparatus are the spring seats. The variation in loss in weight of seat is, therefore, a criterion of the wear resistance to abrasion under constant pressure sliding service and performance obviously varies accordingly.

SUMMARY AND DISCUSSION

A summary of results obtained from these tests not only confirms what has been known about plastic flow of high (14 per cent) manganese steel when subjected to heavy pressure when in sliding motion, but it also establishes the fact that even under an apparently more favorable structural condition (martensitic) it compares unfavorably with case hardened steel. The variation in Brinell hardness has little, if any, influence upon its resistance to abrasion under steady pressure. There is one factor in favor of manganese steel which should be mentioned, namely,

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that its entire sectional dimension gives practically the same value of wear resistance while the depth of a wear-resistant case in case hardened steel is rarely more than $\frac{3}{2}$ inch to $\frac{1}{8}$ inch.

The method of testing was ideal for a direct comparison of the two materials, but has no bearing upon other service application of manganese steel where pounding or crushing is encountered.

CONCLUSION

In concluding it can be stated: (1) That case hardened steels are more resistant to wear than 14 per cent manganese steel in service under high pressure and sliding motion, but free from shock or pounding; (2) it has been shown that this is true for carburized low carbon steels as well as for carburized medium carbon steels and applies to 14 per cent manganese steel castings in their various structural modifications depending upon thermal treatments; (3) evidently a toughened or austenitic grain structure of 14 per cent manganese steel is of no benefit, nor is a martensitic structural condition of advantage if produced by heat treatment. I believe the latter conclusion is contrary to the general conception of the wearing qualities of this material; (4) the favorable results from case hardened steels obviously depend upon the care exercised in the carburizing and heat treatment of the steel and only from a properly conducted process can similar results be consistently expected.

Written Discussion: By John H. Hall, Taylor-Wharton Iron and Steel Company, High Bridge, New Jersey.

A cursory reading of Mr. Merten's interesting paper would lead a person unfamiliar with the subject to suppose that, in cases of metal-to-metal abrasion and wear, a case-hardened article is better than one of 12 per cent manganese steel. The well-known fact, however, that in such service as the gear drives of cement mills, manganese steel literally knows no competitor, indicates that Mr. Merten's conclusions hold good only for service such as characterized his particular test.

It is well known that 12 per cent manganese steel in the heat-treated condition is comparatively soft, about 200 Brinell, and that it does not resist wear well unless the wear is accompanied by severe pressure or pounding. It is perhaps not so well known that under severe cold working the hardness of the surface layers of manganese steel increases rapidly to about 500 Brinell, and that it is largely because of this hardening that manganese steel resists so successfully wear accompanied by heavy pressure.

This change of surface hardness, moreover, continues as a manganese

steel article wears down, the new metal hardening rapidly as fast as it is exposed by wear, so that the rate of wear is uniform throughout the life of the piece. This change in hardness is due to an alteration of the physical state of the metal, whose nature has so far been a matter of speculation, but which has now been explored quite thoroughly by F. F. Lucas in collaboration with the writer. The exact nature of the metallographic change involved we are not yet ready to make public. Suffice it to state that it is not at all the same alteration that is produced by annealing the steel at 575 degrees Cent., as Mr. Merten did in one of his experiments, with the idea of rendering the steel harder. Such an annealing raises the hardness of manganese steel to about the same extent as cold working does, but does not bring about the same metallographic alteration. It is not to be expected, therefore, that Mr. Merten would have found any improvement in wear after such an annealing.

At the comparatively low pressure used in Mr. Merten's experiments, little if any hardening of the surface layers of the manganese steel was to have been expected, and it is not surprising that the wear of the case hardened steel under these conditions was found to be slower than that of the 12 per cent manganese steel—the conditions of service were not such as manganese steel is suited for.

In such service as metal-to-metal gear drives, where the loads are very heavy, especially when much dirt and grit are present, it will be found that manganese steel castings harden rapidly on the surface, and will outwear from five to ten times any other material. This is especially true when the total allowable wear of the parts amounts to an inch, for instance, because the wearing rate of the manganese steel is constant, whereas a surface-hardened article wears slowly until the shallow surface layer of hard metal is gone, and thereafter wears very rapidly.

A rough criterion of whether a particular class of service has or has not been suitable for manganese steel is—"Did the manganese steel harden on the surface under the conditions to which it was exposed?" If it did not, some other material is generally preferable. It would be of interest if Mr. Merten would report the hardness of his manganese steel parts, before and after testing.

Author's Reply

In order to reply to Mr. Hall's discussion, I would like to call attention to the significance of some of the factors he mentions and as we observed them, during our tests. Whether the magnitude of pressures applied is high or not is a matter of opinion. These pressures were the maximum encountered in this service and they do not produce surface hardening or render the surfaces of manganese steel wear resistant. Manganese steel, therefore, is not aiding performance in locomotive service of this type by virtue of wear resisting surface characteristics developing during service. But, as I have stated before, the usefulness of manganese steel under pounding conditions are not questioned. The hardening under such conditions is probably due to a precipitation of carbide from the solid solution.

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MANUFACTURE OF MALLEABLE IRON

By DR. ALBERT E. WHITE

Abstract

The author in this paper gives consideration to the composition, physical properties, and structural constitution of malleable iron and sets forth the results of numerous experiments in a series of tables and shows, by means of photomicrographs, the changes in structure of cast iron when brought to various temperatures. A series of curves show the graphical expression of time-temperature relations for equilibrium of cast iron of varied carbon and silicon content. The author attaches much importance to the cooling down process.

A summary sets forth the variation in time required to produce equilibrium in iron-carbon alloys of the composition usually used in making malleable cast iron, the combined carbon for equilibrium conditions and the maximum cooling rate compatible with the successive maintenance of equilibrium for high, medium and low silicon alloys through a wide range of temperatures.

INTRODUCTION

MALLEABLE iron has been manufactured for well over one hundred years. "The art of making malleable castings, as that term is understood in America, was probably unconsciously discovered by Seth Boyden while attempting to practice Reaumur's method in Newark, New Jersey, in 1826." It has only been within the past few years, however, that the scientific world has understood with any real degree of certainty the changes occurring in the iron when undergoing conversion from white iron to malleable iron.

The manufacture of malleable iron may properly be divided into two parts (a) the production of the iron castings and (b) the annealing of these castings to make them malleable. The iron (in the form of pigs and scrap) is usually melted in a furnace of the reverberatory type, called an air furnace, and when thoroughly molten and of proper composition the metal is cast into green sand molds. The composition of the iron should be such that the castings, when cold, contain no graphite. This, of course,

A paper presented before the Cleveland Chapter of the Society. The author, Dr. Albert E. White, is director of the department of engineering research, University of Michigan, Ann Arbor, Michigan.

results in a casting which is hard and brittle. If these castings are heated to a red heat for a considerable length of time and slowly cooled the properties of the metal are entirely changed. The once hard and brittle castings are now much softened and are quite malleable. This, in brief, is the manner in which malleable iron is produced in this country.

In England and on the Continent malleable iron differs in some respects from the American product. The European iron is known as "white heart" malleable iron, while the American product is called "black heart" malleable iron. The general cycle for the production of castings is the same in both cases. However, chemical composition of the two irons is different and the annealing operation may differ to some extent. In Tables I and II, taken from Hatfield's "Cast Iron in the Light of Recent Research," a good idea of the comparative compositions and properties of the two products is given.

Table I
Physical Properties of Malleable Irons

	European	American "Black Heart"
Yield point tons per square inch....	12-18	10-20
Maximum stress—per square inch...	19-29	16-26
Elongation, per cent	6-2	15-4½
Reduction of area, per cent.....	6-2	15-4½

Table II
Chemical Composition of Malleable Irons
In Per Cent

	European Heavy	"Steely" Medium	Fracture Light	American Heavy	American Medium	"Black Heart" Light
Carbon	2.8-3.5	2.8-3.5	2.8-3.5	2.8-3.5	2.8-3.5	2.8-3.5
Silicon	0.50-0.70	0.60-0.80	0.70-0.90	0.40-0.60	0.6-0.8	0.8-1.0
Manganese ..	Up to 0.15	Up to 0.15	Up to 0.15	Not over 0.4	Not over 0.4	Not over 0.4
Sulphur	Not over 0.35	Not over 0.35	Not over 0.35	Not over 0.07	Not over 0.07	Not over 0.07
Phosphorus ..	Not over 0.2	Not over 0.2	Not over 0.2	Not over 0.2	Not over 0.2	Not over 0.2

PROPERTIES OF MALLEABLE IRON Composition

The composition of malleable iron is largely determined by the

class of castings to be produced. In castings having heavy sections, the rate of cooling will be much slower than is the case of castings having thin sections. Inasmuch as the tendency to precipitate graphite is dependent on the cooling rate and the silicon content, it is evident that if high silicon iron is used in heavy castings, conditions most favorable to the precipitation of graphite are produced. If graphite is precipitated when the metal is solidifying it will be in that form in which it occurs in gray cast iron; which is a form much more deleterious to good physical properties than is the case when in the form of temper carbon. For this reason heavy sections are generally poured from metal lower in silicon than would be the case if the sections were thin. Intricate castings require more fluid metal than do the simpler shapes and iron of higher carbon content is, therefore, used. All these things must be considered in determining the composition of the metal to be cast. The following figures give the approximate limits of variation in composition of American malleable iron.

Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Sulphur Per Cent	Phosphorus Per Cent
2.30-3.40	0.40-1.10	0.10-0.30	Not over 0.07	Not over 0.20

Physical Properties

While the present paper is not primarily concerned with the physical properties of malleable iron, those properties are so intimately connected with the chemical composition and metallographic structure that it may be well to say a few words on this subject.

The best source of information on the subject of tensile properties is undoubtedly the reports of the American Malleable Castings Association. A perusal of their monthly bulletins reveals the fact that of the test bars submitted daily by each of the sixty odd members of the association, only two to three per cent fall below the American Society for Testing Materials specification of 45,000 pounds per square inch tensile strength and 7.5 per cent elongation.

Fig. 1 gives the results obtained by the American Malleable Castings Association of all member companies for the years 1918, 1919, 1920 and 1921, and the requirements of the American Society for Testing Materials. An examination of this chart shows that the average of the association's values are well in excess of

the American Society for Testing Materials requirements. Further the chart shows the splendid improvement in the physical properties of the association's castings since 1918. Between 1918

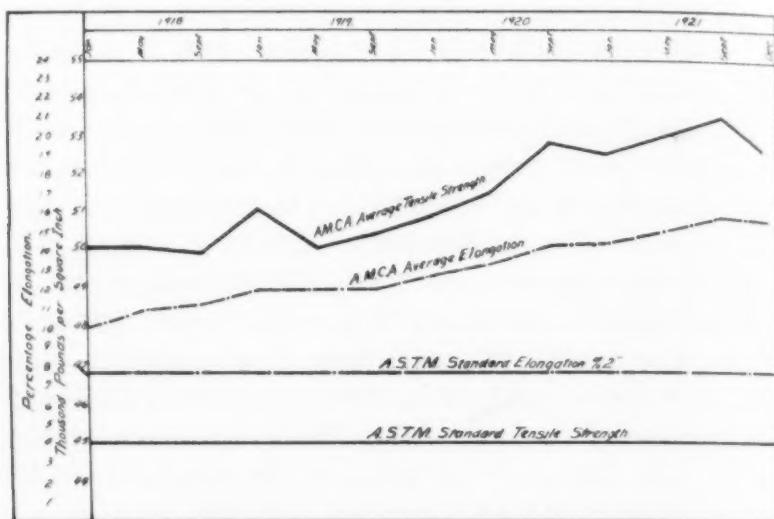


Fig. 1—Curves Showing a Comparison between the American Malleable Castings Association Physical Properties Requirements with those of the American Society for Testing Materials Physical Properties Requirements, 1918-1921.

and 1921 the tensile strength of the castings increased from approximately 49,000 pounds per square inch to about 53,000 pounds per square inch. The ductility as measured by per cent elongation increased from around 9 per cent to around 15 per cent.

Structural Constitution

In order to have a full appreciation of the changes which occur during the annealing of a piece of white cast iron to produce malleable iron (see Figs. 2 and 3) one must turn to the metallographic structure at the various stages of the anneal. The original white iron is usually composed of pearlite and cementite.

If this iron is heated above the critical range the pearlite is changed to austenite, while cementite undergoes no immediate change. However, graphite and austenite and not cementite and austenite are the stable phases in this instance of the iron carbon series. Hence cementite is gradually transformed into graphite by dissolving through the austenite and precipitating out as graphite. The carbon content of austenite is determined by the temperature and, hence, the amount of combined carbon present under equilibrium conditions corresponds to the SE line of the

iron carbon diagram.

Figs. 2
Fig. 3—

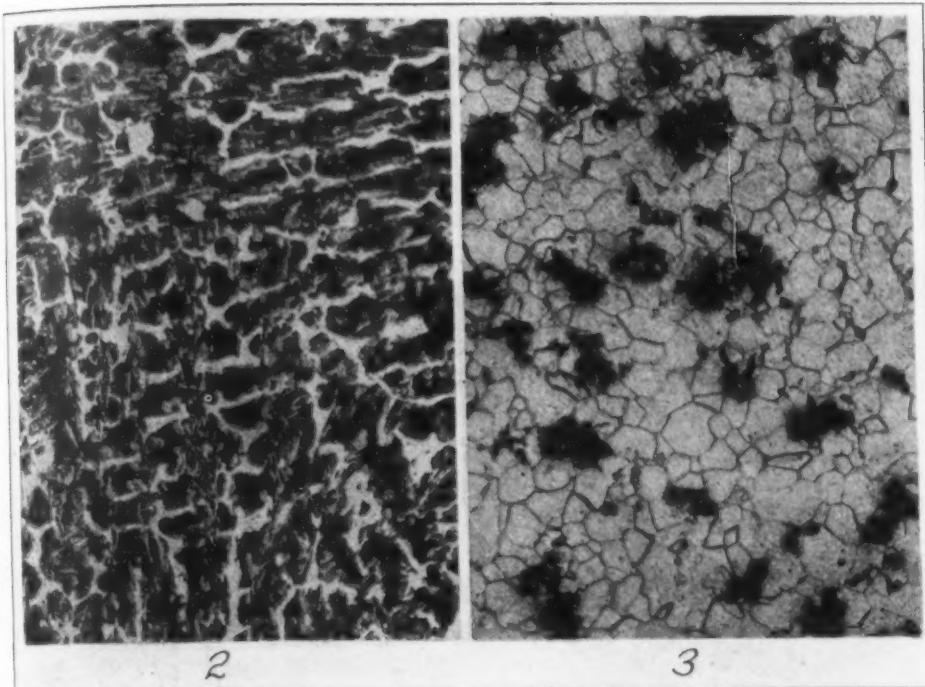
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The iron alloy diagram

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iron carbon diagram (see Fig. 4). In white iron to be malleablized there is a certain amount of silicon, and this moves the SE line



Figs. 2 and 3—Structures of Cast Iron Before and After the Malleablizing Treatment.

Fig. 2—Structure of White Iron Before Annealing.

Fig. 3—Structure of Malleable Iron After Annealing. Specimen Etched. Mag. 100x.

to the left. Hence the combined carbon content for equilibrium values in malleable iron are lower than would be the case were the alloys free from silicon.

The influence of silicon on the combined carbon content of iron alloys is shown by reference to the accompanying iron carbon diagram (see Fig. 4).

In addition to the lines generally given three more have been placed in the austenite field. The lines marked 4.22 and 2.23 per cent silicon are taken from the work of Charpy and Conrune-Thenard, and the line marked 0.82 per cent silicon is taken from data established at the University of Michigan. Careful inspection reveals the fact that silicon pushes the SE line to the left in an approximate proportion to the amount of silicon present.

Silicon raises the critical point of cast iron but the evidence on this subject is as yet not complete enough to make any generalizations. The critical point of the 0.82 per cent silicon iron occurs

at 1395 degrees Fahr. (757 degrees Cent.) and the solubility of carbon changes from 0.50 per cent to zero per cent at this point. This last statement is based on the following facts:

Annealing experiments carried on at 1400-1410 degrees Fahr. proved that the combined carbon content for equilibrium condi-

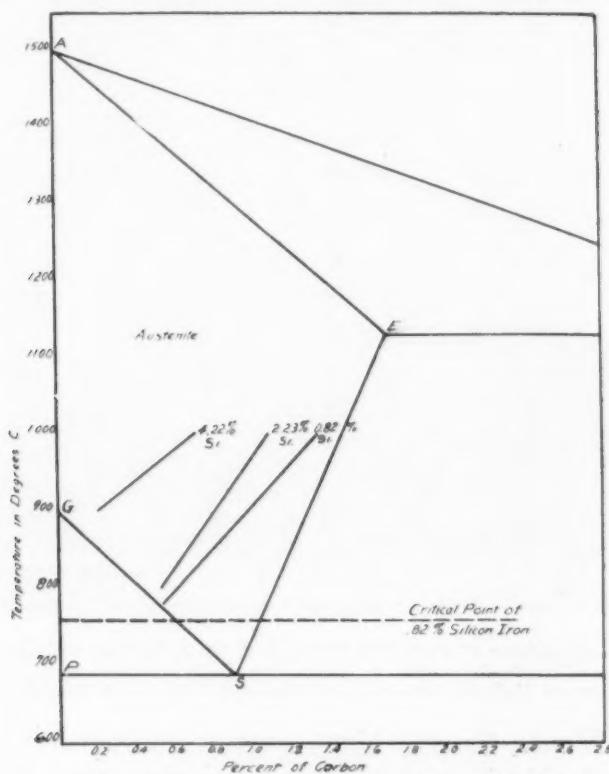


Fig. 4—A Portion of the Iron-Carbon Diagram.

tions was very close to 0.50 per cent. During the time, experiments were being carried out on equilibrium conditions at 1400 degrees Fahr. an anneal was run at 1390-1400 degrees Fahr. After 320 hours' heating the combined carbon had dropped to 0.13 per cent as against equilibrium conditions at 1400-1410 degrees of 0.50 per cent after 275 hours' heating. There is no doubt that had the 1390-1400 degrees Fahr. anneal been continued for 25 to 50 hours longer, complete precipitation of the combined carbon would have been effected.

RESULTS OF EXPERIMENTS AT THE UNIVERSITY OF MICHIGAN

General

It was for the purpose of determining the equilibrium conditions for cast irons of malleable iron compositions that work

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was undertaken on this general problem in the laboratories of the University of Michigan. A few of the results obtained are presented. For convenience, these results have been divided into—

- (a). The heating up period
- (b). The at heat period
- (c). The cooling down period.

Heating Up Period

Little work has been done on the heating up period, inasmuch as this period is generally determined by the type of annealing equipment employed, rather than by metallurgical considerations. It has been found, however, that if the heating up period is of relatively short duration (less than 5 hours) the temper carbon particles formed are somewhat larger and more irregular than is the case when the heating up period is relatively long (over 25 hours). This effect, however, appears to have little influence on the physical properties of the final product.

The At-Heat Period

The *at-heat* period is conditioned by the at-heat temperature and the composition of the metal. Experiments were made at 1800 degrees Fahr. (972 degrees Cent.), 1700 degrees Fahr. (927 degrees Cent.), 1600 degrees Fahr. (870 degrees Cent.), 1500 degrees Fahr. (815 degrees Cent.) and 1400 degrees Fahr. (769 degrees Cent.). Irons of three different compositions were used in these experiments. The average analyses are given below:

Table III
Chemical Composition

Type	Total Carbon	Si.	Per Cent	S	P
			Mn.		
Low C. Low Si.	2.35	0.60	0.17	0.041	Less than 0.20
Low C. High Si.	2.45	0.90	0.25	0.050	Less than 0.20
Med. C. Med. Si.	2.70	0.82	0.21	0.050	Less than 0.20

The samples used in these experiments were brought quickly to the desired temperature and maintained there until no further change occurred in the condition of the carbon, i. e., until equilibrium was established.

The procedure employed to determine equilibrium at 1600 degrees Fahr. will be quite sufficient to illustrate the method used in

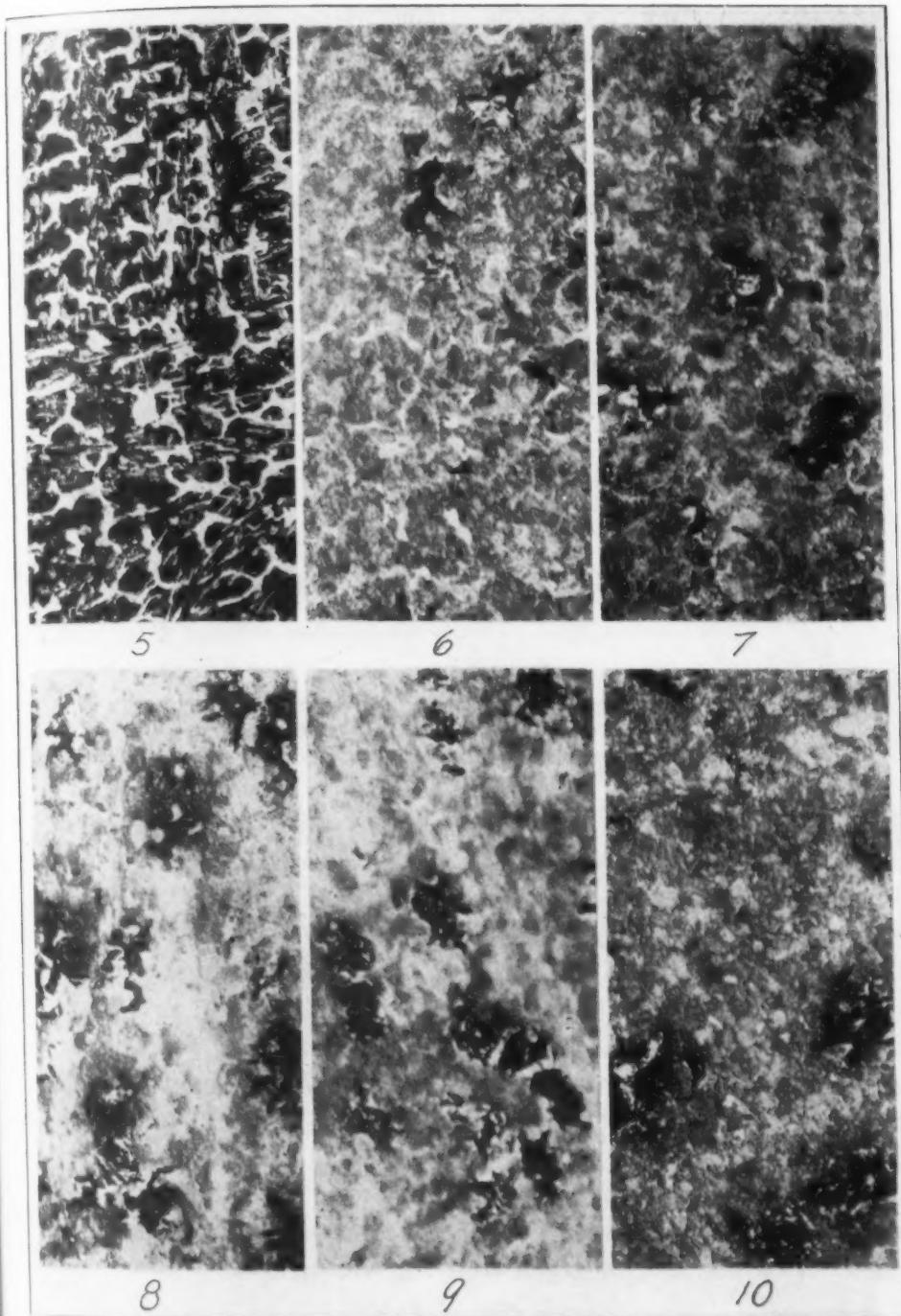
determining equilibrium at the other temperatures. A set of bars was placed in a small heating furnace and brought to 1600 degrees Fahr. as rapidly as possible. Conditions were such that seven hours were required to bring the metal to heat. After one bar had been held at heat for five hours, making a total length of time in the furnace of twelve hours, it was removed and examined for chemical composition with respect to total carbon and graphitic carbon, the combined carbon being ascertained by difference, for its metallographic structure and for its physical properties. Other bars were removed after having been at heat for ten hours, fifteen hours, twenty hours, and twenty-five hours. All of them were air-cooled so that the carbon might approach as nearly as possible its condition at the instant of removal. The results of this work show that for the given iron in question equilibrium is substantially reached after the iron has been at heat for fifteen hours. Under these conditions, therefore, there would be no further advantage or benefit gained by holding the metal at the given temperature for a longer period. The analyses of the respective bars for total carbon, graphitic carbon and combined carbon, are given below:

Sample	Total Carbon Per Cent	Graphitic Carbon Per Cent	Combined Carbon Per Cent
Untreated	2.45		2.45
5 hours at heat	2.49	1.20	1.29
10 hours at heat	2.42	1.55	.87
15 hours at heat	2.44	1.65	.79
20 hours at heat	2.38	1.63	.73
25 hours at heat	2.45	1.69	.76

The results of the physical tests are as follows:

Sample	Tensile Strength in lbs. per sq. in.	% Elongation in 2 inches	Reduction of Area
5 hours at heat	74,500	0.5	0.7
10 hours at heat	76,200	0.5	0.6
15 hours at heat	77,900	0.5	0.3
20 hours at heat	81,500	1.0	2.6
25 hours at heat	82,400	1.0	0.7

It is realized that all of the physical properties mentioned, although showing good tensile strength, are defective in elongation. It must be kept in mind that this material represents the condition of metal when removed at the maximum annealing temperature and it is believed that all metal in this condition with similar treatment would possess similar properties. It is only



Figs. 5-10—Changes in the Structure of White Cast Iron When Brought to 1600 Degrees Fahr. in Seven Hours and Held at 1600 Degrees Fahr. for 5, 10, 15, 20 and 25 Hours. Samples were Air-Cooled. All Samples Etched. Magnification 100x. Fig. 5—White Iron as Received. Fig. 6—Five Hours at Heat. Fig. 7—Ten Hours at Heat. Fig. 8—Fifteen Hours at Heat. Fig. 9—Twenty Hours at Heat. Fig. 10—Twenty-five Hours at Heat.

when the combined carbon is much further reduced by slow cooling that the relatively high ductilities are secured.

Photomicrographs showing the appearances of the irons in their respective stages are presented in Figs. 5 to 10 inclusive.

This experimental procedure on the three different grades of iron just mentioned and at the temperatures previously stated,

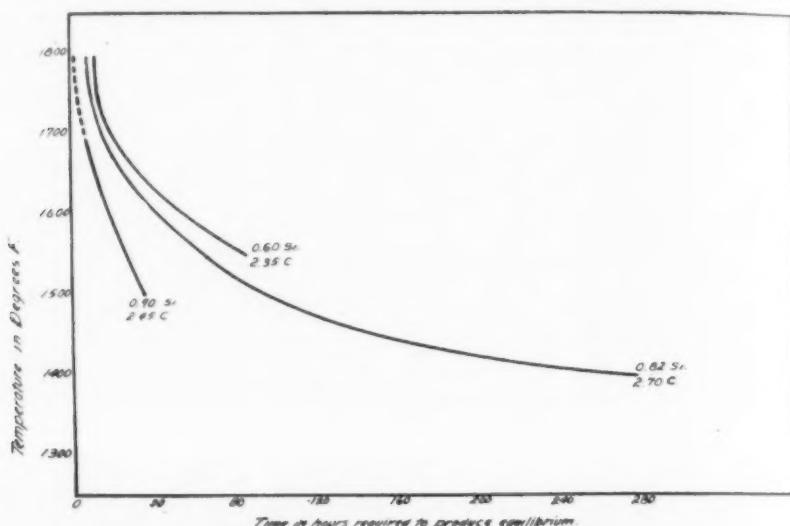


Fig. 11—Curves Showing the Influence of Temperature and Silicon on the Time Required to Produce Equilibrium.

has made it possible to prepare curves showing the influence of temperature and silicon on the time required to produce equilibrium conditions. These curves are given in Fig. 11. A careful examination of the chart shows that silicon materially reduces the time required for a given iron to reach equilibrium. For instance, an iron containing 0.60 per cent silicon and 2.35 per cent total carbon, required 130 hours at 1500 degrees Fahr. to reach equilibrium, whereas an iron containing 0.90 per cent silicon and 2.45 per cent total carbon required but 35 hours at 1500 degrees Fahr.

Fig. 11 further shows that equilibrium is reached in a much shorter time at the higher temperatures than at the lower temperatures. For instance, a given iron containing 0.82 per cent silicon and 2.70 per cent total carbon to reach equilibrium at 1800 degrees Fahr. required but eight hours, but it required seventy-two hours at 1500 degrees Fahr. and two hundred and seventy-five hours at 1400 degrees Fahr.

The combined carbon necessary for equilibrium for each of

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1600° F.

1500° F.

1400° F.

the given temperatures, is given in Table IV and is graphically set forth in Fig. 12. An examination of this data shows that the

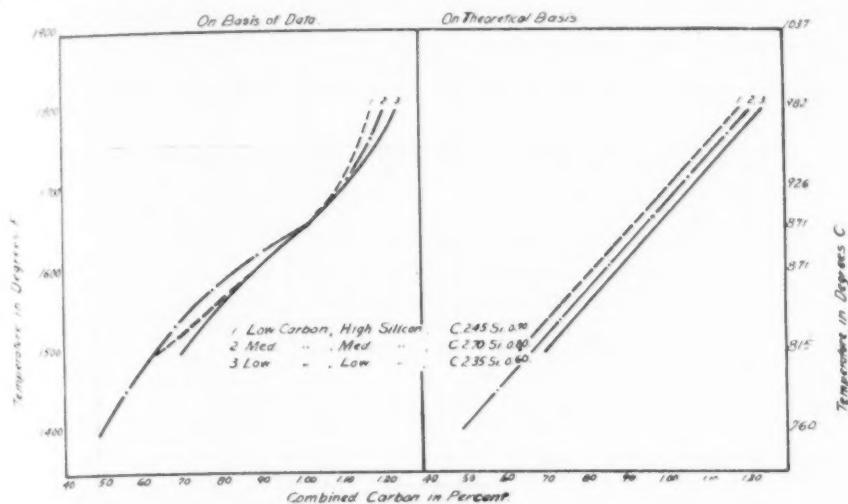


Fig. 12—Curves Showing the Influence of Composition on Equilibrium.

lower the annealing temperature, provided the temperature is above the critical temperature, the lesser the amount of the combined carbon remaining in equilibrium. For instance, the com-

Table IV

Annealing Time and the Combined Carbon in Equilibrium for three malleable iron compositions when heated at 1800, 1700, 1600, 1500 and 1400 degrees Fahr.

Temperature	Low C.&Si. Low C.& High Si. Medium C.&Si.			Time required to produce Equilibrium. Comb. Carbon for Equilibrium.	
	1800° F.	10	4 or less	8	
1700° F.	1.25	1.19	1.21	1.21	Comb. Carbon for Equilibrium.
	20	5	15	15	Time required to produce Equilibrium.
1600° F.	1.09	1.08	1.10	1.10	Comb. Carbon for Equilibrium.
	60	20	50	50	Time required to produce Equilibrium.
1500° F.	0.89	0.88	0.84	0.84	Comb. Carbon for Equilibrium.
	130	35	72	72	Time required to produce Equilibrium.
1400° F.	0.70	0.64	0.64	0.64	Comb. Carbon for Equilibrium.
			275	275	Time required to produce Equilibrium.
			0.49	0.49	Comb. Carbon for Equilibrium.

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combined carbon for the iron containing 2.70 per cent total carbon and 0.82 per cent silicon for equilibrium at 1400 degrees Fahr. was 0.49 per cent; the combined carbon for equilibrium at 1800 degrees Fahr. for the same iron was 1.21 per cent.

From these results it is to be noted that the carbon content

Development of Empirical Equation.

corresponding to equilibrium conditions at the various temperatures is changed only little (only 0.05-0.08 per cent) by changing the silicon from 0.55 to 0.90 per cent. However, the time required to produce equilibrium is greatly changed. The total carbon content, provided it is between 2.30 per cent to 3.00 per cent, likewise seems to have little effect upon the combined carbon content for equilibrium conditions or on the time required to produce equilibrium conditions.

The data from which the time-temperature curve for the medium carbon and the medium silicon iron was plotted has been used as the basis for the development of a mathematical expression

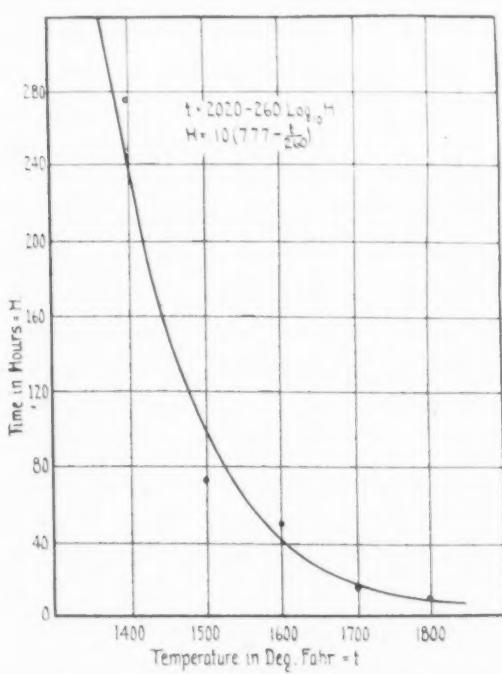


Fig. 12a—Graphical Expression of Time-Temperature Relation for Equilibrium of Cast Iron. Carbon 2.70 per cent, Silicon 0.82 per cent.

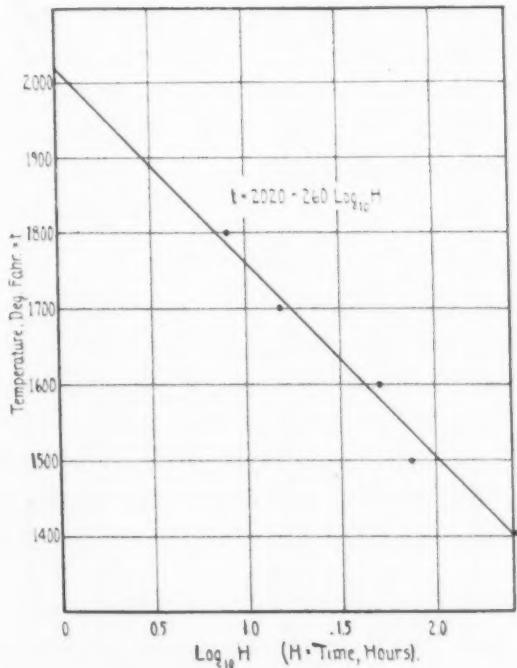


Fig. 12b—Graphical Expression of Time-Temperature Relation for Equilibrium of Cast Iron. Carbon 2.70 per cent, Silicon 0.82 per cent.

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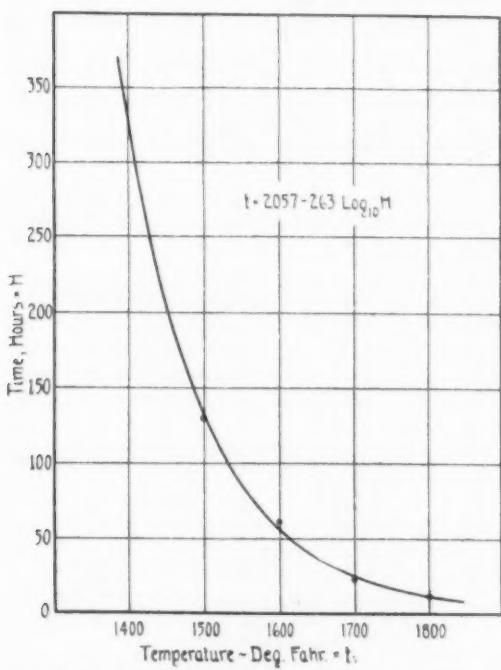


Fig. 12c—Graphical Expression of Time-Tempera-
ture Relation for Equilibrium of Cast Iron.
Carbon 2.35 per cent, Silicon 0.60 per cent.

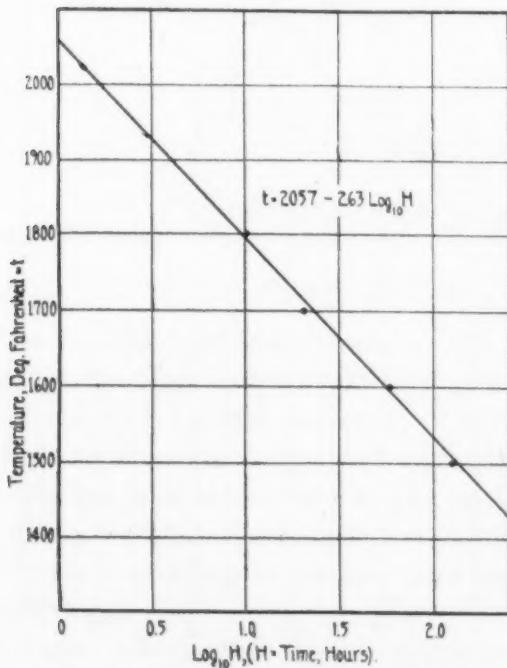


Fig. 12d—Graphical Expression of Time-Tem-
perature Relation for Equilibrium of Cast Iron.
Carbon 2.35 per cent, Silicon 0.60 per cent.

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by which to state the relationship between the temperature and the time at heat.

The general form of equation which best fits this data is—

$T = m \log_{10} H + b$.

T = temperature in degrees Fahrenheit.

m = constant (For the 2.70 C. and 0.82 Si. Composition—260)

b = constant (For the 2.70 C. and 0.82 Si. Composition 2020)

H = time in hours.

The method employed in working out this formula and various additional forms of expressing the equation is incorporated with this report.* For a further composition of iron namely one containing 2.35 per cent carbon and 0.60 per cent silicon the constants become $m = -263$ and $b = 2057$.

From the preceding mathematical developments the time required for the procurement of equilibrium at any given temperature in the malleablizing range for these two grades of iron may be ascertained.

Figs 12a, 12b, 12c and 12d have been drawn on the basis of the above calculations. Figs. 12a and 12b present the relationship for the 2.70 per cent carbon and 0.82 per cent silicon iron in terms of time and temperature and temperature and logarithm of time, respectively. Figs. 12c and 12d present the data similarly for the 2.35 per cent carbon and the 0.60 per cent silicon iron. It is appreciated that with only four determinations available from which to present the data for these latter curves there may not be the same probable accuracy as exists in the case of those plotted in Figs. 12a and 12b.

Cooling Down Period

The cooling down period is conditioned by the same factors governing the at-heat period. The desired cooling rate is the maximum compatible with the successive maintenance of equilibrium conditions. This rate is most rapid at high temperatures and with high silicon irons; and is slowest at temperatures close to the critical range and with low silicon irons. In an iron of the composition—

Total Carbon	Si.	Mn.	S.	P.
2.70	0.82	0.21	0.050	0.186

the following cooling rates as given below and in Fig. 13 were found to be maximum.

*For this development the author wishes to thank Mr. C. H. Berry of "Power."

Temperature Range
 1700°-1600° F.
 1600°-1500° F.
 1500°-1400° F.
 1400°-1300° F.

Approximate Limits
 of Cooling rates per Hour
 25°-35° F.
 25° F.
 10°-15° F.
 5°-8° F.

An increase of the silicon content makes possible a much more rapid cooling rate. This is shown by the fact that an iron of the composition—

C.	Si.	Mn.	S.	P.
2.45	0.90	0.25	0.050	0.186

was perfectly malleablized when cooled at a rate of 28 degrees Fahr. per hour from 1500 degrees Fahr. to below the critical range

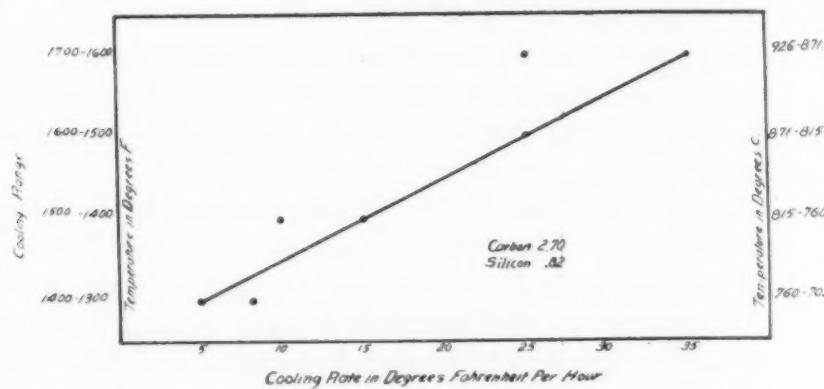


Fig. 13—Curve Showing the Influence of Temperature on the Cooling Rate.

whereas the iron just discussed, containing 0.82 per cent silicon, had to be cooled at a much slower rate, in order to procure perfect malleablization.

The structures of a number of irons brought to 1600 degrees Fahr. in thirty-six hours, held at 1600 degrees Fahr. for fifteen hours and then cooled at different rates, are given in Figs. 14 to 20 inclusive.

The results of the chemical analyses for carbon at the end of fifteen hours at heat and at the various temperatures at which the test bars in their process of cooling were removed, are given below:

Sample	Total Carbon	Graphitic Carbon	Combined Carbon
16-15-A	2.40	1.63	.77
16-15-1400-A	2.37	1.75	.62
16-15-1300-A	2.40	1.81	.59
16-15-1100-A	2.45	2.32	.13
16-15-1000-A	2.39	2.32	.07
16-15-900-A	2.40	2.35	.05
16-15-S	2.40	2.36	.04

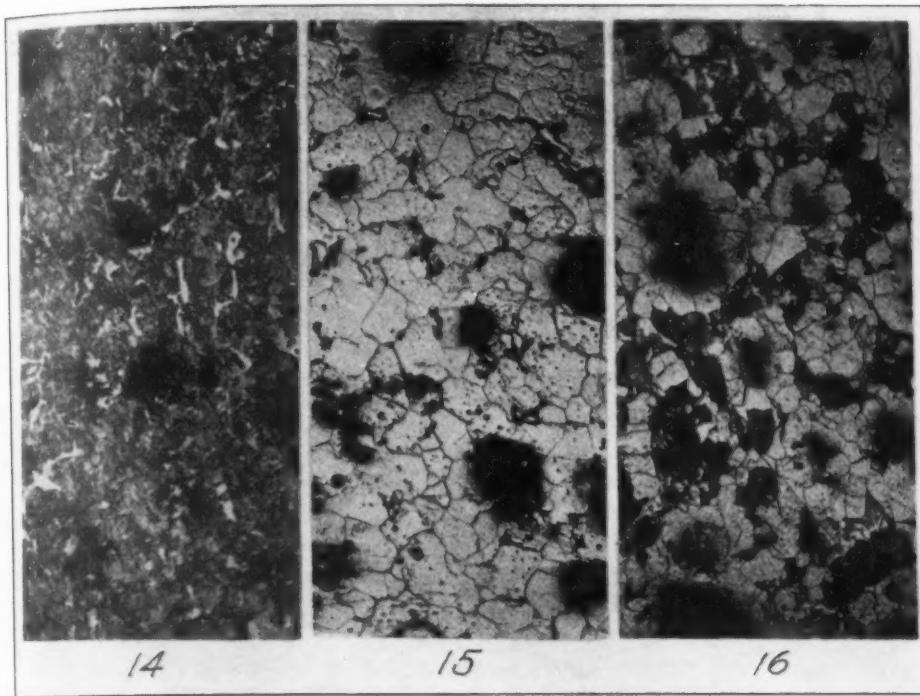
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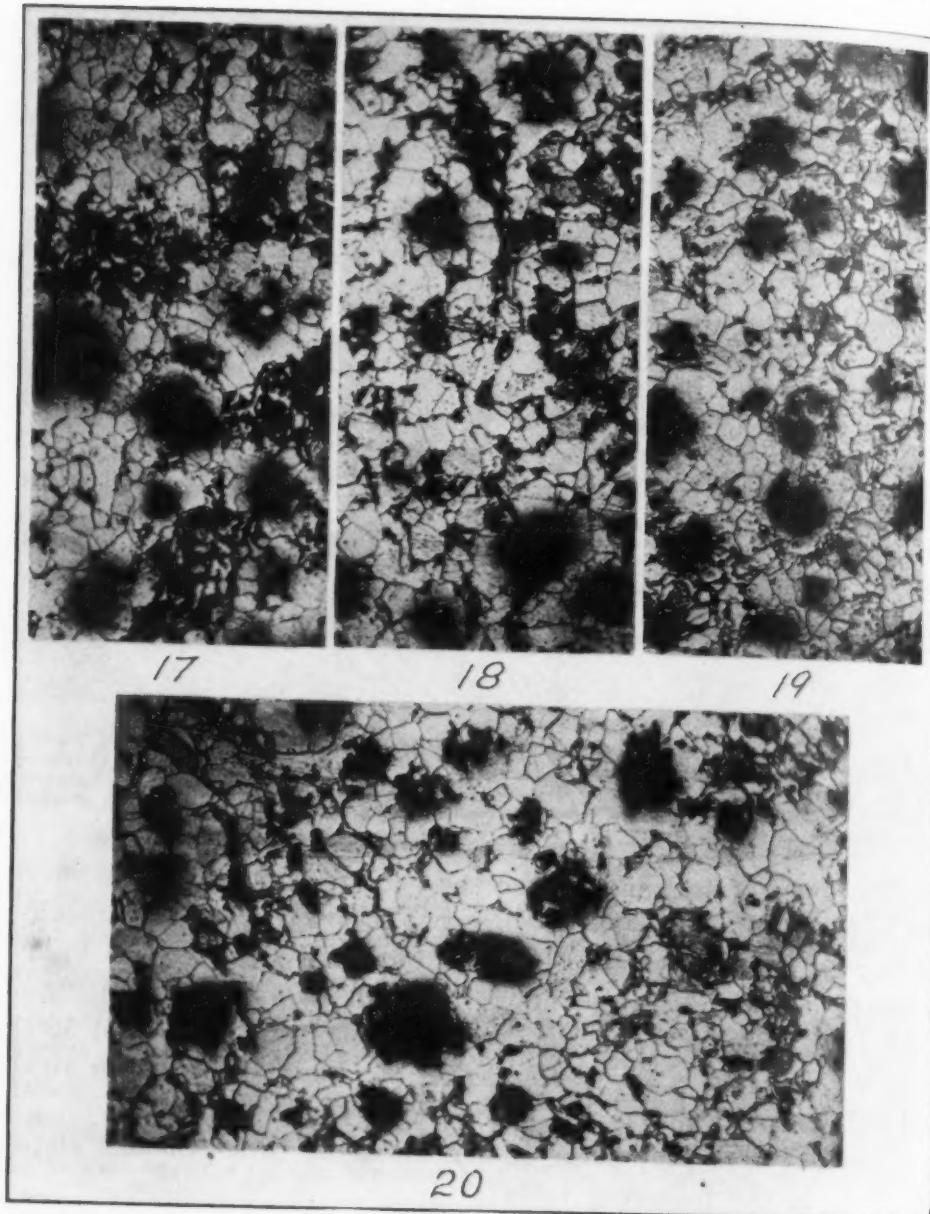
Figs. 14-16—Influence of Varying Cooling Conditions on White Cast Iron After Having Been Brought to 1600 Degrees Fahr. in 36 Hours, Held at that Temperature for 15 Hours and then Cooled as Follows: Fig. 14—Air-Cooled from 1600 Degrees Fahr. Fig. 15—Furnace-Cooled to 1400 Degrees Fahr., then Air-Cooled. Fig. 16—Furnace-Cooled to 1300 Degrees Fahr., then Air-Cooled.

The rates of cooling between the various temperatures worked out so that between 1600-1400 degrees Fahr. it was substantially 92 degrees Fahr. per hour; between 1400 and 1300 degrees Fahr. it was 66 degrees Fahr. per hour; between 1300 and 1100 degrees Fahr. it was 54 degrees Fahr. per hour; between 1100 and 1000 degrees Fahr. it was 44 degrees Fahr. per hour and between 1000 and 900 degrees Fahr. it was 50 degrees Fahr. per hour.

The physical properties of the metal at these various steps are given in the following table:

Sample	Tensile strength in lbs. per sq. in.	% Elongation in 2 inches	% Reduction of area
16-15-A	77,500	2.0	0.9
16-15-S-1400-A	70,000	3.0	1.4
16-15-S-1300-A	59,400	6.0	5.3
16-15-S-1100-A	55,500	8.0	5.2
16-15-S-1000-A	54,200	10.0	7.3
16-15-S-900-A	54,400	9.0	5.6
16-15-S	51,000	6.5	6.6
16-15-S	48,000	8.0	4.2

It will be noted that all of the samples taken out at a tem-



Figs. 17-20—Influence of Varying Cooling Conditions on White Cast Iron After Having been Brought to 1600 Degrees Fahr. in 36 Hours, Held at that Temperature for 15 Hours and then Cooled as Follows: Fig. 17—Furnace-Cooled to 1100 Degrees Fahr., then Air-Cooled. Fig. 18—Furnace-Cooled to 1000 Degrees Fahr., then Air-Cooled. Fig. 19—Furnace-Cooled to 900 Degrees Fahr., then Air-Cooled. Fig. 20—Furnace-Cooled from 1600 Degrees Fahr.

perature of 1100 degrees Fahr. or lower have excellent tensile strength and good elongation. Unfortunately all of the test bars used in this experiment showed shrinkage in the center of the bar. Because of this condition the elongation, although above seven and one-half per cent, the value established by the American Mal-

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leable Castings Association as indicative of good malleable iron, are appreciably lower than would otherwise have been the case. It is believed that were the shrinkages not present all of the test bars taken out at a temperature of 1100 degrees Fahr. or lower would have had an elongation better than fifteen per cent. Whether or not this condition would have been true with the test bar removed at 1300 degrees Fahr. is a question. It is believed, however, that there is too much combined carbon in that test bar to anticipate as great an elongation.

SUMMARY

(1) The time required to produce equilibrium in iron carbon alloys of the composition commonly used in making malleable cast iron varies from less than 4 hours at 1800 degrees Fahr. with high silicon alloys to 275 hours at 1400 degrees Fahr. for medium silicon alloys and longer for low silicon alloys.

(2) The combined carbon for equilibrium conditions varies from 1.20-1.25 per cent at 1800 degrees Fahr. to 0.47-0.50 per cent at 1400 degrees Fahr. and is only slightly affected by the ordinary variations in silicon.

(3) The maximum cooling rate compatible with the successive maintenance of equilibrium was found to be 28 degrees Fahr. per hour for the lower cooling range (1500-1300 degrees Fahr.) for 0.90 per cent silicon alloys and faster for the upper temperature ranges. For an 0.82 per cent silicon alloy the rate varies from 25-30 degrees Fahr. at 1700-1600 degrees Fahr. down to 5-8 degrees Fahr. for 1400-1300 degrees Fahr.

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SOLIDIFICATION OF STEEL IN THE INGOT MOLD

BY ALEXANDER L. FEILD

Abstract

The linear rate of solidification of steel and the location and shape of the shrinkage cavity, with certain simplifying assumptions, are treated mathematically. From the mathematical standpoint, the methods employed are capable of further development to apply to actual mold practice, provided some of the physical properties of steel and mold material (cast iron) at high temperatures are determined experimentally. In the case of steel poured at its melting temperature, the maximum rate of solidification is shown to be inversely proportional to the square root of the elapsed time, measured from the moment of contact between liquid steel and mold wall, and the distance through which solidification has progressed directly proportional to the square root of the elapsed time. The effect of degree of superheat above the melting temperature and of mold wall thickness upon solidification rate are discussed. Finally, equations defining the surface of the shrinkage cavity are derived for mold chambers of (a) uniform cross-section, (b) ordinary taper and (c) inverted taper, and the important effect of pouring rate and taper upon pipe formation emphasized.

PURPOSE AND SCOPE OF THE PAPER

HERE may be found in the literature a record of numerous researches and observations on the solidification of steel, considered (1) as a physico-chemical process involving the formation of austenitic solid solution or delta iron from the liquid, with its attendant phenomena of crystal growth and of segregation of dissolved constituents and of nonmetallic inclusions; (2) as a step in the manufacture of ingots or castings in which the transition of a confined mass of liquid steel to a solid of greater density, brought about through cooling of its surface, gives rise to complex problems of pipe formation and its prevention by sinkhead feeding; and (3) as a similar step in manufacture which in the case of "open" and of incompletely "killed" steels is complicated by gas evolution and the occurrence of blow holes. When the independent effects of steel composition, pouring rate, pour

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, Alexander L. Feild, was physicist with the United Alloy Steel Corporation, Canton, Ohio.

ing temperature, and mold design are considered also, the exceedingly involved nature of the general subject is apparent.

The present paper does not pretend to treat of the solidification of steel in any extensive manner nor to cover exhaustively any one of its numerous aspects. Rather, it contains certain results of a preliminary search after basic principles underlying the solidification of steel within the mold chamber and its methods, so far as are included herein, are entirely mathematical.

The fact that such methods would not appear to have been employed hitherto to any significant extent makes unnecessary any specific references to previous work. However, the writer wishes to acknowledge his indebtedness to such authors as Howe, Hadfield, Brearley, and Gathmann for much general and detailed information and to a number of others from whom by actual contact in the industry on practical problems many facts and original observations have been obtained.

GENERAL ASSUMPTIONS

In order to simplify the calculations which follow, steel will be considered as though it were a pure metal, solidifying at a definite temperature instead of through a temperature interval, and no account will be taken of the particular case where gas is evolved during freezing. The material of the mold, which is usually cast iron, will be assumed to possess the same values of thermal conductivity, density, and specific heat displayed by the steel after solidification, or, to be more exact, the same value of thermometric conductivity or diffusivity (thermal conductivity divided by the product of density and specific heat).

Also, it is assumed that contact between the mold wall and the contained steel persists until solidification is completed. Actually, of course, thermal contraction of the ingot shell during its fall to temperatures below the freezing point causes the surface of the steel to withdraw from the wall as soon as the radial component of thermal stress exceeds the ferrostatic pressure.

These particular general assumptions, to the extent by which they fail to represent actual conditions, affect only those calculations below those which have to do with rate of solidification. They can be dispensed with, if desired, in deriving the equations of the shrinkage cavity.

In the shrinkage cavity calculations, on the other hand, it

is consistently assumed that the top surface of the ingot suffers no loss of heat due to radiation and convection, or, rather, that there is a horizontal surface impervious to heat at the top of the mold chamber. Actually, radiation and convection losses cause the formation of a crust of solid steel over the liquid below. This crust, however, rather effectively retards further heat loss as the development of the shrinkage cavity proceeds beneath it.

Finally, attention is called here to the fact that the effective coefficient of contraction on passing from the liquid to the solid state, which occurs in the shrinkage cavity equations, is not equal to the true coefficient as measured at the melting temperature, but is smaller. This arises from the partial neutralization of the true isothermal contraction at the change of state by the opposing, progressive contraction of the solidified shell. The true coefficient is approximately 0.06, whereas the effective coefficient observed may be around 0.02.

INGOT SOLIDIFICATION VERSUS ISOTHERMAL CRYSTALLIZATION

The well known theories relative to crystallization rate are in the main built around the central idea of isothermal conditions. Most frequently they are further restricted to crystallization of a solid from a liquid solvent. The crystallization of sugar from its aqueous solution, either by evaporation or cooling is a complete instance in point. Whether crystallization is initiated from suspended nuclei or from the walls of the container, no appreciable temperature gradient exists within the solution. Where the complete crystallization of a substance has been studied, it has been customary to observe the process as it occurs in containers of capillary dimensions or under other conditions which approach the isothermal one. Tammann and his school in particular have made many valuable contributions, theoretical and experimental, in this field. As far as possible the factors influencing rate of crystallization are reduced to (1) number of available nuclei, (2) degree of supercooling or supersaturation, and (3) the inherent crystallizing power of the substance at the temperature in question.

The rate of solidification of steel in the mold chamber, in sharp contrast to the process conducted as above, is determined entirely by the rate at which heat is conducted away from the liquid metal. The number of available nuclei in the liquid metal

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and its crystallizing power are more than great enough to provide all the liberated heat of fusion which can escape by thermal conduction.

MAXIMUM RATE OF SOLIDIFICATION OF STEEL IN THE MOLD CHAMBER

Consider two infinite bodies, one (A) composed of liquid steel at its melting temperature and the other (B) solid steel at room temperature (or mold wall), each with a single plane surface and with these surfaces placed suddenly in contact. Heat will flow from (A) to (B) and solidification will proceed in a direction normal to this plane surface.

Let T_m = initial temperature of (A), degrees Cent.

T_o = initial temperature of (B), degrees Cent.

t = time in seconds, measured from the instant of contact of (A) and (B).

L = latent heat of fusion, gram-calories per gram.

k = thermal conductivity, gram-calories per degree Cent. per square centimeter per centimeter⁻¹.

d = density, grams per cubic centimeter.

s = specific heat, gram-calories per degree Cent.

v = linear velocity of solidification, centimeters per second.

If W is the quantity of heat liberated by solidification per second for each square centimeter of solidifying surface, then

$$W = Lvd \quad (1)$$

The quantity of heat conducted away from unit surface per second may be calculated by the aid of Fourier's series and is likewise equal to W . The resulting equation is

$$W = \frac{k(T_m - T_o)}{1.77 \left(\frac{kt}{ds} \right)^{.5}} \quad (2)$$

Equating (1) and (2), and transposing.

$$v = \frac{(T_m - T_o)}{1.77 L t^{.5}} \cdot \left(\frac{ks}{d} \right)^{.5} \quad (3)$$

Equation (3) expresses the relation between the maximum velocity of solidification and (1) the difference between the melting temperature of the steel and the initial mold wall temperature, or $(T_m - T_o)$; elapsed time (t) measured from the instant of contact; (3) latent heat of fusion (L) of the steel; and (4)

the physical properties of thermal conductivity (k), specific heat (s), and density (d), each with reference to the solid steel. Items (1) and (2) can be measured directly with accuracy. Item (3) is known to be equal to approximately 70. Of the three physical properties grouped under item (4), specific heat only has been determined up to the melting point.

Temp. Degrees Cent.	Specific heat	Temp. Degrees Cent.	Specific heat
0	0.105	900	0.159
100	0.117	1000	0.145
400	0.151	1100	0.145
700	0.185	1200	0.145
800	0.159	1400	0.145

The density of solid iron, which is known to be 7.8 at ordinary temperatures, decreases to a value close to 7.4 at its melting temperature. The thermal conductivity of iron at ordinary temperatures is equal to about 0.16 and is known to decrease comparatively rapidly at high temperatures. At the melting temperature this value is probably around 0.05.

Actually, equation (3) holds rigidly only for constant values of k , s , and d . To modify this equation to take care of the variations of these physical properties with temperature over the range T_m to T_o would present mathematical difficulties even if these variations were accurately known in each instance. However, because of the fact that the three symbols occur under the square root sign in equation (3), an error in assigning the proper values affects the value of v to a relatively small degree. Assuming $k = 0.07$, $s = 0.15$, and $d = 7.5$, and substituting in equation (3),

$$v = \frac{(1535-35)}{(1.77)(70) t^{0.5}} \cdot \left[\frac{(0.07)(0.15)}{7.5} \right]^{1/2}$$

$$\text{or } v = 0.44 t^{-0.5} \quad (4)$$

From equation (4) may be calculated the maximum rate of solidification, in a direction normal to the mold wall, at any time.

By simple integration, equation (4) yields the equation governing the relation between total elapsed time and total distance through which solidification has progressed, or

$$D = 0.88 t^{1/2} \quad (5)$$

where D is the distance in centimeters, taken normal to the wall of the mold chamber.

From (5) it would appear, for instance, that at the end of the first second solidification cannot have progressed further than 0.88 centimeter, and that at the end of 60 seconds the maximum thickness of solidified steel cannot exceed 7.8 centimeters. The reciprocal of rate of solidification, as well as the thickness of solidified steel, increases parabolically with elapsed time.

EFFECT OF DEGREE OF SUPERHEAT ABOVE THE MELTING POINT UPON SOLIDIFICATION RATE

The specific heat of liquid steel in the neighborhood of its freezing point is equal to about 0.15, while the latent heat of fusion is 70. In other words, the heat set free by the solidification of one gram of steel is equal to that abstracted from 467 grams of liquid steel in cooling through one degree within the temperature range above and close to the melting point. It is obvious, therefore, that, if the liquid steel is at a temperature above its melting point when brought into contact with the mold wall, the effect upon rate of solidification is equivalent to substituting for $t^{1/2}$ in equation (4) the expression $(t^{1/2} - t^{1/2}_0)$, where t_0 is the time which elapses before the liquid steel is cooled to its freezing temperature. (It is assumed, here as elsewhere, that the liquid steel is of uniform temperature throughout). The same applies likewise to thickness of solidified metal and to equation (5). Now if, for instance, the slab of liquid steel in contact with the mold wall has an initial thickness of 25 centimeters and is initially at a temperature of 50 degrees above the melting point, then each square centimeter of the wall must dissipate $25 \times 6.9 \times 0.15 \times 50 = 1290$ calories before solidification begins. Since the latent heat is 70 calories, a 50-degree superheat has a time equivalent corresponding to the solidification of $\frac{1290}{70}$

$= 18.4$ grams of steel per square centimeter or to a distance of solidification equal to $\frac{18.4}{7.4} = 2.5$ centimeters. From equation

(5) initial solidification through a distance of 2.5 centimeters takes place in 8 seconds.

If, therefore, a 50-degree superheat is taken, subject to the assumption regarding available volume of liquid steel, it follows that solidification would not begin until the end of 8 seconds and that at the end of the ninth second (the first second of actual sol-

idification) the thickness of metal solidified would be equal to $0.88 (9)^{\frac{1}{2}} - 0.88 (8)^{\frac{1}{2}}$ or to 0.17 centimeters, as against 0.88 centimeters for the first second of solidification for liquid steel initially at its melting temperature. The thickness of solid metal formed in 60 seconds would be 4.9 centimeters as against 7.8.

The very great effect of degree of superheat upon solidification rate is evident from such considerations as the above.

EFFECT OF MOLD WALL THICKNESS UPON RATE OF SOLIDIFICATION

In the preceding section a mold wall of infinite thickness was assumed, or a mold wall so thick that the temperature rise on its outer surface is too small appreciably to affect the rate of freezing of the confined liquid. Elementary considerations point to the fact that for the first brief period of solidification the effect of thickness of mold wall is negligible and that all molds of ordinary design should give approximately the same initial rates as would a mold of infinite wall thickness. The effect of mold thickness becomes observable as solidification proceeds and is of increasing importance as solidification nears completion and also as the cross-section of the mold chamber increases.

As a matter of fact, a certain time is required for the rise in temperature of the inner wall to have any effect whatever upon the temperature of the outer mold wall. A certain period must elapse before the heat flow reaches the outer wall. As a result, there is a definite interval of time during which the steel freezes precisely as it would in a mold of infinite wall thickness. This interval is calculable by the aid of Fourier's series. By means of the same device the effect of finite wall thickness upon solidification after the lapse of this time interval may be computed approximately. It is planned to give the results of such calculations in a subsequent paper.

THE EQUATION OF THE PIPE OR SHRINKAGE CAVITY

The derivation of equations which define the shape and location of the pipe or shrinkage cavity as a function of mold chamber coordinates of the mold chamber, taking the longitudinal ingot axis as the Y-axis and the basal plane as the XZ-plane.

Mathematically, the simplest case (Case I) is that of a cylindrical mold chamber with nonconducting surfaces at both top and bottom. In this case, as in others where the chamber is of

circular cross-section, the shrinkage cavity may be represented by a plane curve, since the cavity is symmetrical with respect to the ingot axis.

It is assumed that the mold chamber is instantaneously filled with liquid metal. Direction of solidification is radial and isothermal surfaces are cylindrical and coaxial with the mold chamber.

Case I.

Let r = radius of mold chamber

h = initial height of liquid in mold

a = effective coefficient of contraction on passing from the liquid to the solid state.

x and y = coordinates of surface of shrinkage cavity, x being measured from the longitudinal ingot axis and y vertically upward from the bottom mold plane.

In solidifying from the point x to the point $(x-dx)$ the total volume of contraction due to freezing is equal to $2axy.dx$. If the free surface of the liquid falls from a point y to a point $(y-dy)$ due to this contraction, then

$$\pi x^2 dy = 2\pi a x y dx,$$

$$\text{or } \frac{dy}{y} = 2a \frac{dx}{x}.$$

Upon integrating,

$$\log y = 2a \log x + C,$$

where C is the constant of integration. Now, $x = r$ when $y = h$. Hence, $C = \log h - 2a \log r$. Substituting this value of C in the above equation,

$$\log y = 2a \log x + \log h - 2a \log r \quad (6)$$

Case II.

In this case rate of solidification upward from the bottom of the mold chamber is at any instant assumed to be equal to that which is occurring radially from the wall. As in Case I, the top surface is non-conducting.

$$\pi x^2 dy = 2\pi a x dx (y - x) + a x^2 dx \quad (7)$$

Equation (7) is a differential equation homogeneous in x and y and can be readily put in proper form for integration by letting

$$y = ux$$

$$\text{and } \frac{dy}{dx} = u + x \cdot \frac{du}{dx} .$$

Substituting these values in equation (7),

$$u + x \cdot \frac{du}{dx} = 2au - a,$$

$$\text{or } \frac{du}{(2a-1)u-a} = \frac{dx}{x} .$$

Integrating and replacing u by y/x ,

$$\begin{aligned} \log x &= \log r + \frac{1}{2a-1} \cdot \log \left[\frac{y}{x} (2a-1) - a \right] \\ &\quad - \frac{1}{2a-1} \cdot \log \left[\frac{h}{r} (2a-1) - a \right] \end{aligned} \quad (8)$$

the constant of integration being determined as before.

Case III.

The ordinary tapered mold chamber has a larger cross-section at the bottom than at the top. The simplest case is that of circular cross-section, with nonconducting top and bottom surfaces.

Let Θ = the angle subtended by the bottom ingot plane and a plane tangent to the curved surface of the mold chamber.
 r_1 = radius of mold chamber at top
 r_2 = radius of mold chamber at bottom

The differential equation defining the shrinkage cavity is

$$\pi x^2 dy = \left[\frac{2\pi x + 2\pi(x + r_2 - r_1)}{2 \sin \Theta} \right] ya dx$$

Upon integration this yields

$$\log y = \log h + \frac{2a \cdot \log(x/r_1)}{\sin \Theta} - \frac{a(r_2 - r_1)}{2.3x} + \frac{ar_2}{2.3r_1} - \frac{a}{2.3} \quad (9)$$

CASE IV.

In the case of the mold chamber of inverted taper where r_1 is greater than r_2 and Θ is greater than 90 degrees, the integrated equation (10) is identical with equation (9) except that the algebraic sign of the third term in the right-hand member, $\frac{a(r_2 - r_1)}{2.3x}$ is plus instead of minus.

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THE NOTABLE DIFFERENCE BETWEEN THE PIPE OBTAINED IN AN
ORDINARY TAPERED MOLD CHAMBER AND IN A CHAMBER
OF INVERTED TAPER

Inspection of the above differential equations shows that the surface of the shrinkage cavity becomes asymptotic to the longitudinal axis of the ingot with decreasing values of x when r_2 is greater than or equal to r_1 . However, when r_2 is less than r_1 (Case IV), the value of dy/dx becomes equal to zero when $x = 0$. In other words, the pipe surface is asymptotic to the ingot axis for the mold chamber without taper and for the ordinary tapered mold chamber, but cuts the axis at right angles at a certain distance above the base in the case of the inverted taper.

Fig. 1 shows the calculated shape and location of the pipe, in longitudinal axial cross-section, in a mold chamber 12 inches high for Cases I, III, and IV. Curve (1) is that of equation (6), Case I, where r is taken as 1.5 inches. Curve (3) is calculated from

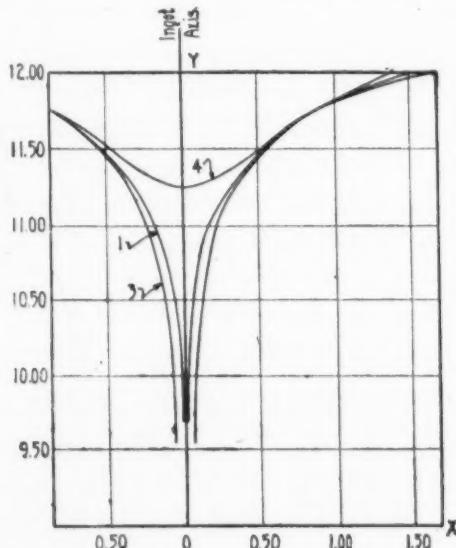


Fig. 1—Curves Showing Calculated Shape and Location of the Pipe in Longitudinal Axial Cross-section in a Mold Chamber 12 Inches in Height.

equation (8) for Case III, taking $r_1 = 2.75$ inches, and $r_2 = 3.25$ inches. Curve (4) is derived from equation (10), Case (IV), where $r_1 = 3.25$ and $r_2 = 2.75$. In each instance, a value of 0.02 has been assigned to the effective coefficient of contraction, a . It may be remarked that the curve for Case II was not plotted because it lies very close to that for Case I.

The calculated values of x and y from which these curves were constructed are given below in Table I.

Table I	Case I	Case II	Case III	Case IV
x	y	y	y	y
1.625	...	...	...	12.00
1.5	12.00	12.00	...	11.96
1.375	11.96	...	12.00	11.90
1.25	11.91	11.80	11.95	11.89
1.00	11.81	11.82	11.83	11.79
0.75	11.67	11.67	11.68	11.68
0.50	11.48	11.53	11.45	11.53
0.25	11.17	10.19	11.03	11.32
0.125	10.86	10.89	...	...
0.10	...	...	10.32	11.25
0.05	10.47	10.50	9.54	(pipe ends
0.01	9.82	9.84	6.00	at $y=11.24$)
0.005	9.55	9.57	3.54	

In the case of the mold chamber without taper (Cases I and II) the pipe extends the entire length of the ingot, although the radius of the pipe, or x , has decreased to 0.005 in. at a distance 9.5 inches above the basal plane. Likewise, in the ordinary tapered mold (Case III) the pipe extends the length of the ingot, the effect of the taper being to enlarge the cross-section of the pipe along its lower extremity. In the case of the ingot of inverted taper (Case IV) the pipe ends abruptly at a distance of 11.24 inches above the base.

EFFECT UPON PIPE OF VISCOUS FLOW IN THE LIQUID STEEL

In the above calculations, the liquid steel has been assumed to flow like a perfect liquid. The existence of the property of viscosity in the liquid delays its downward movement to a negligible degree at first, but, as the cross-section of the pipe section in contact with the liquid decreases in radius, viscous flow becomes an important factor and discontinuities in the lower part of the pipe can appear, at least in the case of ingots which do not have an inverted taper.

PIPE FORMATION IN MOLD CHAMBERS OF CROSS-SECTION OTHER THAN CIRCULAR

Equations (6), (8), (9), and (10) were derived from a consideration of mold chambers of circular cross-section. They are

the equations of the curves intersected on the surface of the shrinkage cavity by a vertical plane through the ingot axis.

The same equations are applicable to any mold chamber of uniform or of uniformly tapered cross-section, provided there is substituted for x the expression $x \sec \Phi$, where Φ is the angle which the intersecting plane of reference through the axis makes with the wall of the mold chamber.

EFFECT OF RATE OF POURING AND RATE OF SOLIDIFICATION UPON THE SHRINKAGE CAVITY

It has hitherto been assumed in the calculations relative to the shrinkage cavity that the mold chamber was initially full of liquid metal before solidification began. Actually, this is never realized in practice, since pouring consumes appreciable time. The mold wall receives a quantity of heat per unit area which increases from top to bottom, and solidification over a certain section of the wall proceeds, before the mold is filled with liquid.

Mathematical treatment of the case where pouring rate and rate of solidification are taken into account in deriving the equation of the shrinkage cavity is exceedingly involved and will not be attempted in the present paper. However, it is more or less obvious that the pouring rate factor is equivalent to a decrease in the cross-section of the ingot which is a maximum at the basal plane and decreases parabolically to zero at the top. This effect is, in other words, in the direction of the inverted taper, and it is conceivable that it may in certain instances be great enough to cause steel in a mold of ordinary taper to pipe in accordance with the law which is always an inherent characteristic of the inverted taper mold. Slow pouring and a high degree of superheat exert opposing influences, so that the advantage of the former may be completely neutralized by the latter.

CONCLUDING REMARK

The foregoing mathematical investigation of the solidification of steel in the mold is not offered with any idea that its methods can supplant the data and observations obtainable by measurement or experience, but in the hope that it may stimulate further work along similar lines and eventually supplement the results of experimental measurement and plant practice to some advantage.

DISCUSSION

Written Discussion: By Emil Gathmann, Gathmann Engineering Co., Baltimore, Maryland.

Mr. Feild's paper is of particular interest and value at the present time when so much is being done to improve the quality of the ingot.

Howe and Stoughton determined experimentally, as early as 1907-08, through an extended series of tests with molten stearine and wax, which materials crystallize and solidify substantially in a manner similar to a well-finished or killed molten steel, various values for X and Y that are relatively in substantial accord with the values given Table I, of Mr. Feild's paper.

In actual steel ingot molding practice we have found that there is a considerable difference in the actual value of X and Y , as compared with the calculated values and those obtained from tests with stearine or wax material. These variations are, we believe, primarily due to the fact that in molding commercial steel ingots the physical contact of mold chamber walls and outer ingot skin is broken shortly after the ingot skin has formed, and the calculated conduction of heat from the molten portion of the ingot to the mold walls is interrupted by an air film, relatively a poor conductor of heat. At any rate we have found that the pipe in all cases, particularly cases II and III, is much wider also deeper than the calculated values especially in medium and large commercial size steel ingots formed entirely in cast iron molds.

The viscosity of steel when just at the point of solidification is a most important factor to be considered in actual commercial ingots formation.

The amount of taper per foot of height in an inverted mold chamber must thus be considerably greater than would appear necessary from Mr. Feild's equations and the values of Y^1 as compared to Y^2 , given in his paper, if the entire ingot is molded in a cast iron mold. If the upper 14 per cent of the ingot is formed in a medium of poor heat conducting, such as a loam or fire clay extension to the ingot mold, the tapers given in Mr. Feild's paper are amply sufficient and in fact more than has been found necessary or advisable in commercial ingot production.

Excessive taper of ingot enlarges the difficulty of reducing the ingot to blooms without increase of surface defects.

We have found from numerous experiments with wax ingots, as well as commercial production of steel ingots, that R^1 as compared with R^2 must be increased empirically as the cross section and height of ingot is increased.

Mr. Feild's mathematical treatment of a very complex subject is a valuable addition to the literature subject of the art and will, I trust, lead to further mathematical discussion of this rather involved subject.

A. L. FEILD: In reply to Mr. Gathmann's discussion, the particular taper selected in the case of this mold was not considered to be the correct taper in practice. It was simply taken as an example showing how the equation was applied; also, the depth of the pipe depends on what value is assumed for the effective shrinkage coefficient. I took this as 0.02, which is actually the coefficient in some steels. However, I believe that in most steels it is

(Continued on Page 338)

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EVIDENCES CONCERNING THE LOCATION OF THE CARBON ATOM IN BOYDENITE

A Contribution to the Study of Graphitization

By H. A. SCHWARTZ

Abstract

The name boydenite was coined some years ago by the author to describe the solid solution of the stable iron-carbon system. In this paper an attempt is made to further support the author's frequently expressed opinion that the solid solutions of carbon in iron in equilibrium with carbon (boydenite) and with cementite (austenite) are essentially different in kind.

On the basis of data from Honda's laboratory calculations are made showing that the densities of austenite and boydenite at about 1650 degrees (900 degrees Cent.) are consistent with certain simple and well-defined differences in atomic arrangement.

It is suggested that boydenite is a solution of carbon in gamma iron in which one atom of the former replaces one of the latter in the face-centered cubic arrangement. Unsuccessful attempts to prepare boydenite at room temperature are reported.

Besides adding to our knowledge of the theory of graphitization this paper is believed to be an original demonstration that a solute atom of any kind can occupy either of two types of location in the lattice of a given solvent.

Since the preparation of the paper, further support of the last stated possibility has been found in certain calculations of Osawa who, however, did not make the same application of his results.

THE author has coined¹ the name boydenite for the solid solution bearing the same relation to the stable alloys of iron and carbon which austenite bears to the metastable alloys. Various reasons have been given (loc. cit.) for considering the two solutions different and the view further supported more recently.²

The evidence referred to shows that the solid solutions in the

¹Conditions of Stable Equilibrium in Iron-Carbon Alloys, Schwartz and co-workers, *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. LXVIII, 916.

²"Notes on A_3 Stable Transformations," Preprint No. 4 of paper presented before the eighth annual convention of the American Society for Steel Treating, September 20-24, 1926.

The author, H. A. Schwartz, is manager of research, National Malleable and Steel Castings Co., Cleveland.

two systems differ not only in maximum carbon concentration at a given temperature but also, for a given concentration in resistivity, thermal coefficient of resistivity, metallographically and in the location of the alpha (beta), gamma transformation and in the location of the A_1 point. The suggestion was also made that in the stable system carbon was probably in solution in some molecular form containing more than a single atom of that element.

Possibly the most important characteristic of a solid solution is the arrangement in space of its constituent atoms. The arrangement of iron atoms in gamma iron, i. e. its space lattice, consists of an arrangement of cubes, whose parameter or length of edge is in round numbers 3.6 Angstrom units (\AA). Each corner of a cube and the center of each of its six faces is occupied by an iron atom, such an arrangement being called "face-centered cubic."

It is the present purpose to consider the available evidence bearing on the location of the carbon atom in the gamma iron lattice to determine, if possible, in what respect boydenite and austenite may differ in this regard.

The classic view of metallic solid solutions involved the concept that atoms of solute were substituted for atoms of the solvent metal with relatively unimportant changes of the latter's space lattice.³ It is now known that in austenite, however, the carbon atom is within the cell and does not occupy any position normally belonging to iron atoms. This demonstration based on the known densities and lattice dimensions of austenite whose carbon content is known is due to Westgren and Phragmen^{3a} and Wever.⁴ Such exceptional behavior of the carbon atom makes it possible that there might be two solutions of carbon in iron, an additive one, austenite, and a substitutional one, which might be boydenite.

Assuming an unaltered lattice parameter the density of a substitutional solid solution of carbon in iron will decrease with increasing carbon content, because the carbon atom is lighter than the iron atom whose place it takes, while that of an additive solid solution will increase, the carbon atom adding to the mass of the solution but not to the volume, and the resulting differences in density should be sufficient to differentiate between the two phases.

³Jeffries and Archer—*Science of Metals*, McGraw-Hill Co.

^{3a}Westgren and Phragmen—X-ray Studies of the Crystal Structure of Steel. *Journal, Iron and Steel Institute*, 1924, Vol. 1, p. 159.

⁴Wever—"Zur Kenntnis des Mischkristalles y-Eisen-Kohlenstoff," *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, Vol. VI, Part 1, Fig. 3.

Two courses are open for investigating these relations; we may either determine the densities in a temperature interval where gamma iron is stable or attempt to preserve the gamma condition at room temperature by the use of suitable alloys. Experiments by the former method, involving the determination of density in molten salt baths by the Archimedean principle have so far presented insurmountable difficulties, although the attempt has not yet been abandoned.

Others, however, have gathered data applicable to the problem. Kikuta⁵ working with an iron containing, Carbon 2.20 per cent, silicon 1.10 per cent, manganese 0.23 per cent, sulphur 0.033 per cent, phosphorus 0.172 per cent found a linear expansion of 2.495 per cent, or a volume expansion 3 times this amount, on heating the metal to 1650 degrees Fahr. (900 degrees Cent.) and maintaining that temperature for nine hours. No further increase in expansion occurred with increasing time. By a short extrapolation from data by the author,⁶ the density of such iron at room temperature is calculated as 7.75. Applying to this the correction for a change of volume of 7.5 per cent as determined by Kikuta we find that his metal at 1650 degrees Fahr. (900 degrees Cent.) had a density of 7.21—compared with water at 77 degrees Fahr. (25 degrees Cent.) as unity.

At 1650 degrees Fahr. (900 degrees Cent.) the solubility of carbon as boydenite is 0.90⁷ and there remains 1.30 per cent of graphite. We may then calculate the density of the boydenite alone by solving the equation

$$\frac{98.70}{X} + \frac{1.30}{2.50} = \frac{100}{7.21}$$

where the density of graphite is taken as 2.50; whence $X = 7.393$.

Honda⁸ finds that a 0.94 carbon steel expands 1.325 per cent on heating to 1650 degrees Fahr. (900 degrees Cent.). This involves an extrapolation from Honda's data which may be considered objectionable. We will recur again to this source of error.

Calculating the density of a 0.90 per cent carbon steel from the

⁵Kikuta—"On Malleable Cast-Iron and the Mechanism of its Graphitization," *Science Reports of the Tohoku Imperial University*, 1926, Series I, Vol. XV, No. 2.

⁶"Some Physical Constants of American Malleable Cast Iron," H. A. Schwartz, *American Society for Testing Materials*, 1919, Vol. XIX, Part II, pp. 247-265 inc.

⁷See foot note 1.

⁸Honda—"On the Thermal Expansion of Different Kinds of Steel at High Temperatures," *Science Reports of the Tohoku Imperial University*, 1917, Series I, Vol. VI, No. 4.

densities of iron and cementite which follow from the writer's data,²² 7.91 and 7.436 respectively, and the increase in volume of 4 per cent observed by Honda will give us a close approach to the density of 1 per cent silicon, 0.90 per cent carbon, austenite at 1650 degrees Fahr. (900 degrees Cent.). Solving the equation

$$\frac{0.90}{7.436} + \frac{99.10}{7.91} = \frac{100}{1.04X}$$

gives a density of 7.55

If the discrepancy between the two calculated values was due only to an error of extrapolation, that error would require to be nearly as great as the entire previous expansion, which is unthinkable.

A solution of carbon in iron containing 0.9 per cent carbon by weight contains 4.1 atom per cent. Substituting carbon atoms (atomic weight 12) for iron atoms (atomic weight 56) involves a diminution of density of $\frac{44}{56}$ as referred to the atoms displaced, or about 3.2 per cent for the alloy in question assuming no material lattice distortion. The adding of 0.9 per cent carbon within the lattice obviously involves an increase of 0.9 per cent in density in the same assumption. The density of the additive and substitutional solid solutions, if of the same lattice parameter, should thus differ by 4.1 per cent. Wever⁹ shows that the presence of four atom per cents of carbon increases the parameter of gamma iron in the ratio of about 3.605 to 3.578 corresponding to a change of density of about 2.24 per cent. This would reduce the difference of 4.1 to 1.86 per cent. The two values calculated for austenite and boydenite differ by 2 per cent which, even in the absence of X-ray crystallograms at high temperature, seems to establish at least a possibility that the two solutions differ in the manner indicated. Unless the presence of carbon atoms of boydenite should very considerably contract the iron lattice, the agreement seems good.

Kikuta observed a contraction of his alloy on cooling to room temperature of 1.4 per cent, a value which, due to the possible further slight separation of carbon, is less by some small undetermined amount than the true coefficient of thermal expansion.

Honda's data give a contraction of about 1.325 per cent for austenite. It thus seems that the coefficients of thermal expansion

²²See foot note 6.

⁹See foot note 4.

of austenite and boydenite are similar, the former being the greater. If we assume boydenite and austenite to be identical then our extrapolation from Honda is in error by the difference between 1.402 and 1.325 which involves an error of about 5 per cent in the change in density of austenite on heating to 1650 degrees Fahr. (900 degrees Cent.) from room temperature which would change the computed density of austenite to 7.535 and involve no change in our general conclusions.

It seems clear therefore that the thermal expansion data gathered by the Japanese investigators show the ratio of the densities of boydenite and austenite to be consistent with the assumption that one is an additive and the other a substitutional solution of carbon in gamma iron.

Both calculations are based on the same values for the densities of iron and cementite so that even rather large changes in these assumed values would not greatly affect the final comparisons which will be largely independent of the absolute accuracy of the assumptions.

Of the elements which may be alloyed with iron to depress the A_3 point below room temperature only nickel seems to hold out hope of establishing stable equilibrium. The late H. R. Payne, in this laboratory, found that an alloy containing

	per cent
Total carbon	3.90
Graphitic carbon	2.67
Manganese	trace
Phosphorus	0.03
Sulphur	0.03
Nickel	19.93
Silicon	0.10

had a density of 7.4957 in vacuo at 68 degrees Fahr. (20 degrees Cent.). E. C. Bain had previously determined for us that such alloys gave X-ray crystallograms of gamma iron without measurable change of parameter. Microscopically, the metal was not homogeneous but contained a striated structure which disappeared without change of composition on quenching from 1650 degrees Fahr. (900 degrees Cent.) leaving a very little of a structure resembling martensite, the density falling to 7.4671. Calculating as before, the density of the metal from the total density and the graphite content, we obtain the value 7.931 or 7.901, accordingly as we use the density before or after quenching. This value is to

be compared with that calculated for an alloy of similar composition with respect to nickel, silicon and combined carbon assuming both a substitutional and additive solid solution of carbon and that nickel is substitutional and silicon additive.

Note:—Other density measurements have shown this to be true of silicon in the case of manganiferous gamma iron, while the solution is substitutional in alpha iron. We are indebted to E. C. Bain and the Union Carbide and Carbon Research Laboratories for the spectrometric work required.

By interpolation from the work of Osawa,¹⁰ we find that alpha iron of this nickel content should have a density of 7.9189. Correcting for the 0.3 per cent decrease in volume accompanying the alpha-gamma change, we obtain the value 7.9427 and adding the 0.1 per cent silicon we obtain the value 7.9506. For an additive solid solution containing 1.23 per cent carbon (austenite) we would obtain the density 8.0484 and for the substitutional solution 7.5920. Calculations founded upon the known density of alpha iron, the ratio of atomic weight of iron and nickel and a postulated constant space lattice gave similar results, the above calculation being preferred as containing fewer assumptions.

Now obviously the apparent density of the solid solution agrees much more closely with the calculation for an additive solid solution than a substitutional one. Experience has shown that the density of ferrite in malleable iron calculated from the density and graphitic content comes out about 0.10 lower than that calculated from the ferrite's composition. If this correction be admissible in this case, the density of the solid solution is between 8.031 and 8.001. The density specimens contained a few nearly microscopic blow holes. Their volume was certainly far less than 0.001, that of the metal but they do involve a slight additive correction of the density. Further, the slight distortion of the gamma lattice in austenite is in the direction of a decreased density so that it is believed well established that the solid solution here encountered is austenite.

Since the preceding was written Osawa¹¹ has published data showing that a part of the carbon in such "austenitic" steels is substituted for metal atoms.

¹⁰Osawa—"The Relation between Space-Lattice Constant and Density of Iron-Nickel Alloys," *Science Reports of the Tohoku Imperial University*, 1926, Series I, Vol. XV, No. 3.

¹¹Osawa—"The Relation between Lattice Constants and Densities of Nickel Steels," *Science Reports of the Tohoku Imperial University*, 1926, Vol. XV, No. 5.

Attention should be given to the fact that 1.23 per cent combined carbon is a surprisingly large amount to find in stable equilibrium with an iron-nickel alloy, for the latter element lowers the carbon solubility in the stable system. The alloy was, however, apparently in equilibrium near 1650 degrees Fahr. (900 degrees Cent.), for heat treatment at that temperature produced no further graphitization. The author is tentatively of the opinion that the nickel alloy was not boydenite. Whether the high nickel content prevents the presence of carbon on lattice corners, or whether the carbon atoms cannot occupy this position at room temperature, but at some higher temperature, range themselves into the centers of the cells, is not clear. It is felt that the facts here cited support the belief that boydenite and austenite are not similar in kind. Also that some evidence has been given as to the possible nature of this difference.

Corroboration of these matters is being sought in other directions particularly by hardness measurements at high temperatures. The energy changes accompanying the change of position of the carbon atom here described must have a bearing upon the equilibria involved, but the writer has been, as yet, unable to consider the thermodynamic aspects of the problem.

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON PART VII

BY F. T. SISCO

Abstract

The present installment, the seventh of the series, discusses the constitution of those iron-carbon alloys containing 1.70 to 4.30 per cent carbon. These alloys are known as the hypoeutectic cast irons and are made up of an eutectic of saturated austenite and cementite: and the excess constituent, saturated austenite. The constitutional changes in this series of iron-carbon alloys when cooled from the molten state to atmospheric temperature are described and their structure illustrated.

OUR discussion of the constitution of steel and cast iron to this point, has included those alloys of iron and carbon known as the steel series containing between 0.01 and 1.70 per cent carbon. We fixed the carbon percentage of 1.70 as the dividing line between steel and cast iron. This was done solely to facilitate our discussion of the underlying principles of equilibrium in the iron-carbon alloys and without reference to any practical consideration. The reason for fixing a carbon percentage of 1.70 as the upper limit for the steels and the lower limit for the cast irons will be readily apparent in the present chapter.

In previous chapters we traced the behavior of these alloys of iron with less than 1.70 per cent carbon when they cooled from above the melting point down to atmospheric temperature. We have noted that a molten alloy of iron and less than 1.70 per cent carbon is a liquid solution of iron carbide, Fe_3C , in molten iron. When this liquid solution cools to the solidification range the mass solidifies as a solid solution of iron carbide (Fe_3C) in iron known as austenite.

The author, F. T. Sisco, is Chief of the Metallurgical Laboratories, Air Corps, War Department, McCook Field, Dayton, Ohio.

Reverting to metallographic terms austenite is a solid solution of varying amounts of cementite in gamma iron. This solid solution cools unchanged until it reaches the transformation ranges where the gamma iron undergoes allotropic change to the beta and alpha form. In these ranges the solid solution adjusts itself to the eutectoid ratio (of 0.84 per cent carbon or 12.5 per cent cementite, Fe_3C) by expelling the excess ferrite (iron) in the case of low carbon alloys or the excess cementite (iron carbide) in the case of high carbon alloys. At atmospheric temperature all of the transformations have been completed, and our normal steel consists of the eutectoid aggregate (pearlite) and the excess ferrite or cementite as the case may be.

SATURATED AUSTENITE

We have described austenite as a solid solution of iron carbide (cementite) in gamma iron. This solid solution may have any percentage of carbon from a trace to the maximum of 1.70 per cent. When austenite contains 1.70 per cent carbon equivalent to 25.5 per cent cementite, it is saturated. Under conditions of equilibrium the gamma iron can hold no more iron carbide in solid solution. When this is the case it is known as saturated austenite.

When saturated austenite containing 1.70 per cent cementite in solid solution cools undisturbed to atmospheric temperature, the cementite in excess of the eutectoid ratio is rejected in cooling resulting in a conglomerate made up of 86 per cent pearlite and 14 per cent free cementite.⁸³

This conglomerate of 6 parts of pearlite and 1 part of cementite resulting from the slow cooling of saturated austenite of 1.70 per cent carbon plays an extremely important part in the constitution of the cast irons. Howe has designated the saturated austenite as primary austenite and calls the conglomerate of 6 parts of pearlite and 1 part of cementite, austenoid. These two terms serve to distinguish saturated austenite from the undersaturated austenite of varying carbon content of the steels.

It is important that we remember that in the solidification of the iron-carbon alloys containing more than 1.70 per cent car-

⁸³1.7 per cent carbon \times 15 = 25.5 = per cent total cementite in steel. Then the ferrite is $100 - 25.5$ or 74.5 per cent. Since all of the ferrite is in the pearlite, 74.5×1.15 (see part V, TRANSACTIONS, Vol. 10, page 812) = 85.6 per cent pearlite. Then the steel contains 85.6 per cent pearlite and 14.4 per cent free cementite.

bon (the cast irons) when we speak of austenite, we always mean the saturated or primary austenite containing 1.70 per cent carbon.

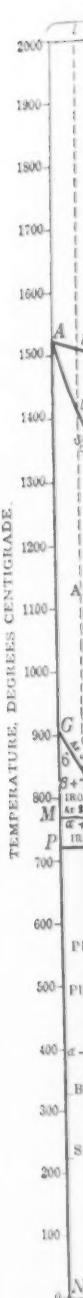
GENERAL FEATURES OF THE IRON-CARBON DIAGRAM APPLIED TO CAST IRON

Fig. 44 reproduced from Howe and Fig. 45 from Sauveur, show the complete iron-carbon diagram. The area in this diagram to the left of the point "E" (Fig. 45) has already been studied. This area describes the solidification and transformations in the steel series. From our previous study we should be able to trace the solidification of any alloy of iron and carbon containing less than 1.70 per cent carbon from a high temperature where it is a liquid solution of iron carbide in iron, down to atmospheric temperature where the metal is an aggregate of crystalline grains of pearlite and excess ferrite or cementite.

Turning now to Fig. 44, we will first view the diagram as a whole, especially that part lying to the right of the point "E" and picturing the solidification and transformations in the iron-carbon alloys containing between 1.70 and 6.67 per cent carbon. Since one part of carbon is equivalent to 15 parts of iron carbide, we are considering now the alloys of iron with 25.5 to 100 per cent iron carbide.

The iron-carbon diagram shown in Fig. 44 (and Fig. 45) is the result of thousands of cooling curves and metallographic examinations of pure iron-carbon alloys. The first diagram was published about 1897. Research work on the diagram has continued almost uninterruptedly to the present day.

The solidification and constitution of the alloys containing between 1.70 and 5.0 per cent carbon has been thoroughly investigated. The mechanism of solidification and the constitution of the alloys containing between 5.0 and 6.67 per cent carbon is more uncertain. Hence the lines AB and AEB in Fig. 44 have been fixed with certainty, while the position of the line BD beyond 5 per cent is still somewhat in doubt. The line ABD is the liquidus above which all of the alloys of iron and carbon are wholly molten. The line AEBC is the solidus, below which the alloys are wholly solid. The area included in the triangles AEB and BDC is the mushy stage. At any temperature included in these areas the alloys are partially liquid and partially solid.



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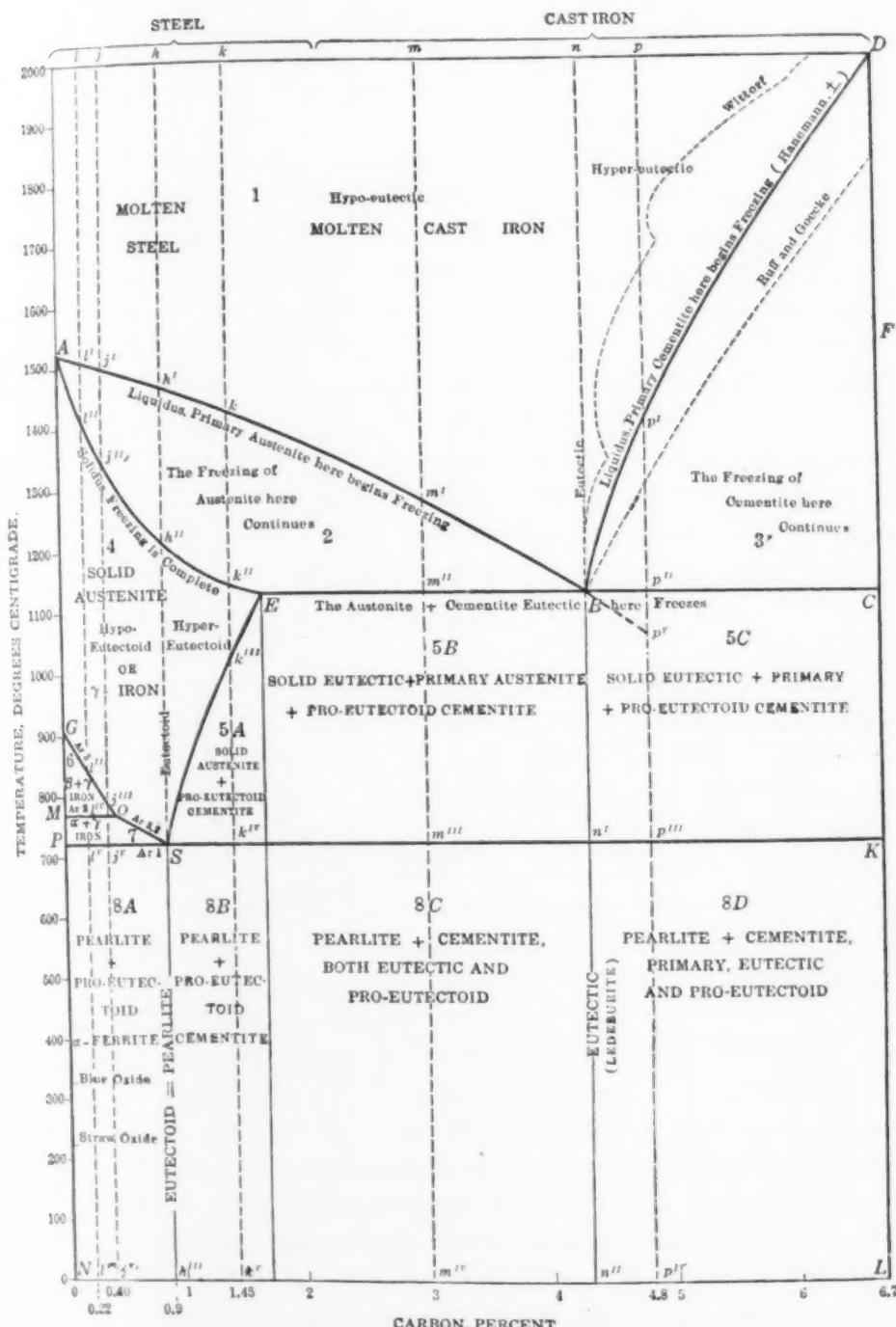
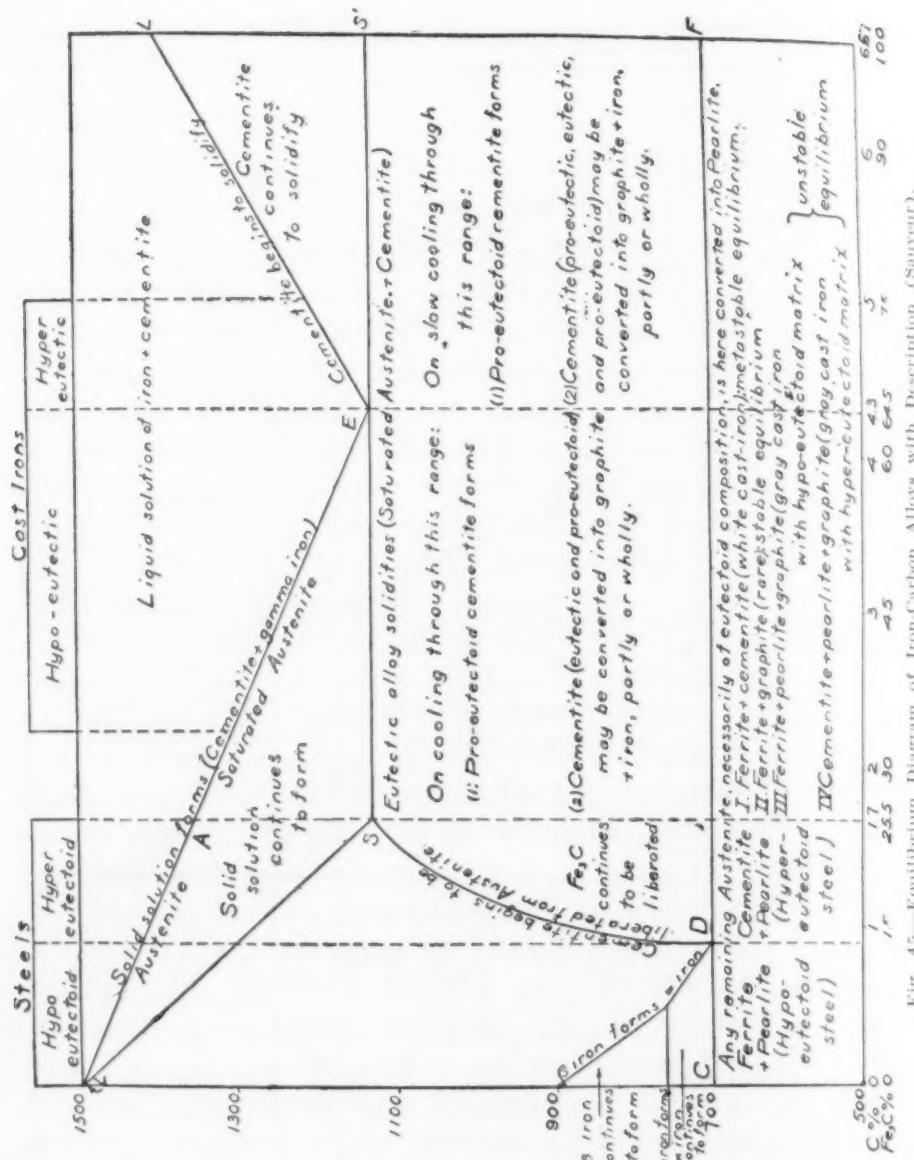


Fig. 44—The Metastable or Cementite-Austenite Iron-Carbon Diagram (Howe).

The line PSK locates the transformation point where the austenite is transformed into pearlite.

The point "B" on the iron-carbon diagram is the eutectic



point where an eutectic iron containing 4.3 per cent carbon freezes unselectively at the constant temperature, 2065 degrees Fahr. (1130 degrees Cent.). Cast irons containing less than 4.30 per cent carbon are known as hypoeutectic; cast irons of more than 4.30 per cent carbon are hypereutectic. The constitution of these three classes of cast iron will be taken up in detail as we proceed with our discussion.

The iron-carbon diagram shown in Fig. 44 is known as the metastable or cementite-austenite equilibrium diagram. In dis-

Discussing this diagram we take for granted that all of the carbon in cast iron is in the form of iron carbide, Fe_3C .

Practical experience has shown us that the carbide is not the most stable form in which the carbon exists in cast iron. Most of our cast irons contain a fairly large amount of elementary carbon in the form of graphite. In a following chapter we will take up the iron-graphite equilibrium diagram and will show that graphite is more stable than cementite; the cementite tends to dissociate in cooling according to the reaction: $\text{Fe}_3\text{C} \rightarrow 3\text{Fe} + \text{C}$. However, it is necessary for us to study the metastable or cementite-austenite diagram shown in Fig. 44 and Fig. 45 in order that we may understand what happens in the solidification of our cast irons of commerce. Actually in our commercial gray iron part of the carbon exists as graphite and part as cementite, hence the solidification of the ordinary iron we use for our castings involves an understanding of both diagrams.

THE IRON-CARBON EUTECTIC

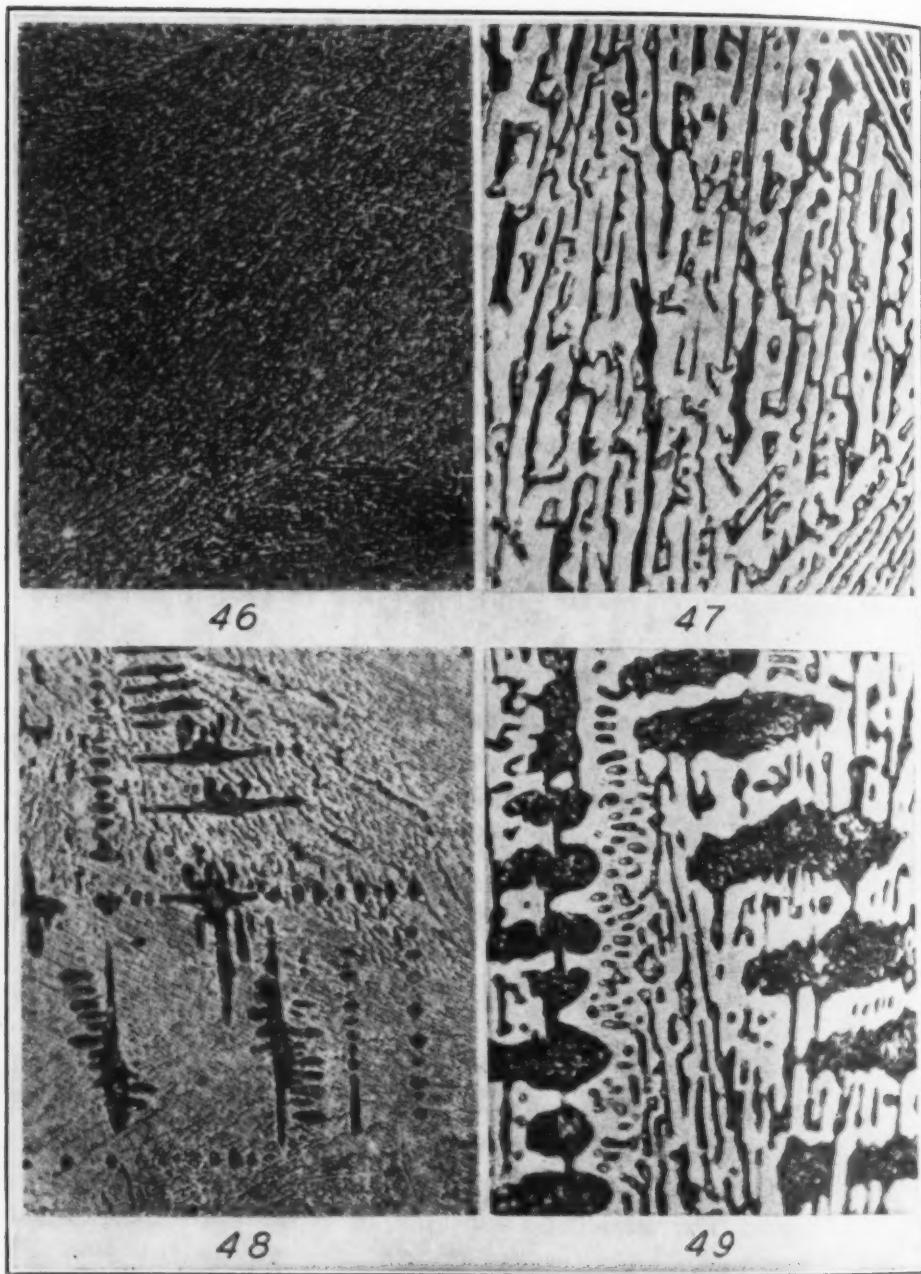
A cast iron at a temperature of approximately 2375 degrees Fahr. (1300 degrees Cent.) is wholly molten and consists of a liquid solution of cementite in iron (see Fig. 45). Now if we let this molten solution cool undisturbed and if conditions are such that none of the cementite breaks up into iron and graphite, when 2065 degrees Fahr. (1300 degrees Cent.) is reached the temperature will remain constant until the whole mass is solid.

Iron containing 4.30 per cent carbon is an eutectic and as is common with eutectics, has a definite solidification point which, as we have already noted, is lower than the solidification point of either component. If we take a specimen of this iron and examine it under the microscope we will see a structure similar to that shown in Fig. 46.⁸⁴ At higher magnification we will note (Fig. 47) that the structure contains two distinct constituents, one light and one dark in color.

Investigation has shown that the light constituent is the definite chemical compound iron carbide, Fe_3C . The dark constituent is saturated austenite or a solid solution of 1.70 per cent carbon or 25.5 per cent cementite in gamma iron.

In our previous study of binary alloys we learned that two

⁸⁴Figs. 46, 47, 48 and 49 from Sauveur, Metallography and Heat Treatment of Iron and Steel. Third edition, 1926, page 432.



Figs. 46 and 47—Photomicrographs of Iron-Carbon Alloy Austenite-Cementite Eutectic. Mag. 65 and 980 Diameters Respectively. Figs. 48 and 49—Photomicrographs of Iron-Carbon Al₂C₃ Hypoeutectic Structure Immediately After Solidification. Dark Crystallites of Saturated Austenite in a Matrix of Austenite-Cementite Eutectic. Mag. 65 and 980 Diameters Respectively.

components in an alloy system may be mutually soluble in each other when liquid, and mutually soluble in each other in all proportions when solid. In the solid state such an alloy is known as

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a solid solution. We also learned that two components of a system may be completely soluble in the liquid state and almost completely insoluble in the solid state. When this happens, we have a condition prevailing whereby an alloy with a definite proportion of these two insoluble components solidifies at a constant temperature similarly to a pure metal, with the exception that it solidifies at a temperature below that of either the components. This alloy is an eutectic or alloy of lowest melting point. In an eutectic alloy either or both components may be a pure metal, a non-metal, a chemical compound, or a solid solution.

Instead of the two components of an alloy being completely soluble (solid solution) or completely insoluble (eutectic) we may have a partial solubility in the solid state. This is the case with the alloys of iron and carbon. When solid, the maximum solubility of iron for carbon is 1.70 per cent or 25.5 per cent cementite. When more than 1.70 per cent carbon is present the excess cementite is insoluble in gamma iron, hence we have a condition in which the saturated austenite forms an eutectic alloy with cementite. In the eutectic, one component is the chemical compound, iron carbide (cementite), the other component is saturated austenite or gamma iron holding 25.5 per cent cementite in solid solution.

STRUCTURAL COMPOSITION OF THE CAST IRON SERIES

If we calculate from the carbon content the percentage of the various constituents in cast iron as we did for the steels we will find that these constituents are present in the amounts shown in Table I.⁸⁵ Glancing at this table for a moment we see that an alloy containing 1.70 per cent carbon contains 100 per cent excess saturated austenite, no eutectic and no excess cementite. This saturated austenite, after having undergone its normal transformation, will be composed of 86 per cent pearlite and 14⁸⁶ per cent pro-eutectoid or excess cementite, which is, of course, equivalent to 74.5 per cent ferrite and 25.5 per cent cementite.

An iron containing 3.0 per cent carbon will consist of 45 per cent cementite and 55 per cent ferrite. Structurally we see from the table that it contains 50 per cent of eutectic, which is made up of 24 per cent saturated austenite and 26 per cent

⁸⁵Howe, *Metallography of Steel and Cast Iron*, 1926, page 67.

⁸⁶Percentages in the table and text are approximate, and are correct to the nearest one per cent.

cementite; and 50 per cent excess saturated austenite. When normal transformations have taken place the 50 per cent excess saturated austenite and the 24 per cent of saturated austenite in

Table I
Structural Composition of the Cast Iron Series

Carbon Per Cent	Austenoid from Saturated Austenite			Austenoid from excess saturated Austenite	Eutectic	Eutectic Austenoid from Eutectic saturated Austenite	Eutectic Cementite	Primary (excess) Cementite	Total Ferrite	Total Cementite
	Total Pearlite	Pro-eutectoid Ferrite (excess)	Pro-eutectoid Cementite (excess)							
1.70	86	0	13.9	100	0	0	0	0	74.5	25.5
1.80	84	0	13.6	96	4	2	2	0	73.0	27.0
1.90	83	0	13.3	92	8	4	4	0	71.5	28.5
2.00	81	0	13.1	89	11	5	6	0	70.0	30.0
2.20	77	0	12.5	81	19	9	10	0	67.0	33.0
2.40	74	0	11.9	73	27	13	14	0	64.0	36.0
2.50	72	0	11.7	69	31	15	16	0	62.5	37.5
2.75	68	0	11.6	60	40	19	21	0	58.75	41.25
3.00	64	0	10.3	50	50	24	26	0	55.0	45.0
3.25	59	0	9.6	40	60	29	31	0	51.25	48.75
3.50	55	0	8.9	30	70	34	36	0	47.5	52.5
3.75	51	0	8.2	21	79	38	41	0	43.75	56.25
4.00	46	0	7.5	12	88	42	46	0	40.0	60.0
4.30	41	0	6.6	0	100	48	52	0	35.5	64.5
4.50	38	0	6.1	0	92	44	48	8	32.5	67.5
4.80	32	0	5.2	0	79	38	41	21	28.0	72.0
6.67	0	0	0	0	0	0	0	100	0	100.0

the eutectic will have been replaced by 64 per cent pearlite and 10.3 per cent pro-eutectoid cementite. This cast iron being hypoeutectic contains the eutectic and excess saturated austenite, but no excess cementite.

An iron containing 4.30 per cent carbon is made up of 35.5 per cent iron (ferrite) and 64.5 per cent iron carbide (cementite). This is the eutectic composition, hence no excess saturated austenite, nor excess cementite will be present. When normal transformations have taken place the 48 per cent saturated eutectic austenite will have been replaced by 41 per cent pearlite and 6.6 per cent pro-eutectoid cementite. In the case of an iron containing 4.80 per cent carbon, there will be present no excess saturated austenite.

The eutectic which is 79 per cent of the structure is composed of 38 per cent saturated austenite and 41 per cent eutectic cementite. This iron is hypereutectic and contains 21 per cent

cementite in excess of that making up the eutectic. The 38 per cent of saturated austenite in the eutectic will undergo normal transformation into 32 per cent pearlite and 5.2 per cent proeutectoid cementite.

It will be noted from an examination of the table that in normal cast irons at atmospheric temperature, we may have two, and in the case of hypereutectic irons, three classes of cementite present. These two or three classes are the same structural constituent, iron carbide, Fe_3C , the distinction between them lies in their aggregation into more-or-less distinct constitutional entities. For example, in the cast iron containing 4.80 per cent carbon which is equivalent to 72 per cent cementite, we have first of all, the cementite associated with saturated austenite in the eutectic, next we have the primary or excess cementite in excess of the eutectic ratio, and finally we have the cementite in the austenite which is in excess of the eutectoid or pearlite ratio. In addition to these three varieties, we have not mentioned the cementite which is associated with the ferrite making up the pearlite.

Ordinarily it is somewhat difficult to visualize this rather complicated structure of the normal cast irons, so in order to make it more plain and to put sufficient emphasis on the various structural constituents we will summarize briefly:

1. The cast iron series are alloys of iron and carbon containing between 1.70 and 6.67 per cent carbon equivalent to 25.5 to 100 per cent iron carbide. If we omit graphite from the discussion for the present, cast iron is made up of iron (ferrite) and iron carbide (cementite). These we may call the ultimate constituents in the alloy.

2. In the solid state the maximum solubility of iron for carbon is 1.70 per cent carbon or 25.5 per cent iron carbide. When the iron is saturated with carbon in the solid state, the constituent thus formed is known as primary or saturated austenite, to distinguish it from the undersaturated austenite of varying carbon content formed in the steel series.

3. When saturated austenite cools to the transformation range the iron undergoes allotropic transformation to the alpha form and the aggregate pearlite, made up of ferrite and pearlite-cementite, is formed. In the saturated austenite there is 14 per cent of cementite in excess of that necessary to form the aggregate

Total Cementite	
5	25.5
0	27.0
5	28.5
0	30.0
0	33.0
9	36.0
5	37.5
75	41.25
0	45.0
25	48.75
5	52.5
75	56.25
0	60.0
5	64.5
5	67.5
0	72.0
0	100.0

pearlite. The conglomerate formed from the transformation of saturated austenite and consisting of 86 per cent pearlite and 14 per cent excess or pro-eutectoid cementite is called by Howe "austenoid".

4. If an iron-carbon alloy contains more than 1.70 per cent carbon (25.5 per cent cementite) there is more than enough cementite to saturate the austenite. Hence this excess cementite forms an eutectic with the saturated austenite. In this eutectic one component is saturated austenite, a solid solution, the other component is cementite, a definite chemical compound.

5. The eutectic alloy in the iron-carbon series contains 4.30 per cent carbon, or 64.5 per cent cementite and consists of 48 per cent saturated austenite and 52 per cent cementite. This austenite which is one component of the eutectic undergoes transformation in exactly the same manner as the primary austenite of our 1.70 per cent alloy, resulting in a conglomerate of pearlite and pro-eutectoid cementite.

With these facts in mind concerning the structural entities present in the normal slowly cooled cast irons free from graphite we are now prepared to discuss the solidification and transformations present in a series of iron-carbon alloys and to examine the structure resulting from this cooling.

SOLIDIFICATION OF HYPOEUTECTIC CAST IRONS

As an example of the solidification of a representative hypoeutectic cast iron we will take the 3.0 per cent carbon alloy, ordinate "M", Fig. 44. At 3630 degrees Fahr. (2000 degrees Cent.) point M, this alloy is a liquid solution of 3 per cent carbon equivalent to 45 per cent cementite in iron. From this temperature the alloy cools unchanged until a temperature of 2320 degrees Fahr. (1280 degrees Cent.) is reached. This is the temperature where the ordinate MM^1 representing the cast iron in question, intersects the liquidus. At this temperature point, M^1 solidification begins by the deposition of solid particles of primary (saturated) austenite containing 1.70 per cent carbon (25.5 per cent cementite). As these solid particles of saturated austenite are deposited from the mother liquor, the remaining liquid is enriched in cementite. As the temperature falls from 2320 to 2065 degrees Fahr. (1130 degrees Cent.) the carbon of the remain-

ing liquid increases along the line AB, until, when the temperature has fallen to 2065 degrees Fahr. (1130 degrees Cent.) the remaining bit of liquid is of eutectic composition which freezes at this temperature. The solid alloy now consists of a solid eutectic (50 per cent) and primary austenite (50 per cent). This process of solidification is graphically illustrated in Fig. 45. Saturated austenite starts to freeze when the temperature reaches the liquidus line LE and continues until it reaches the temperature of the solidus SE.

As this alloy containing 50 per cent eutectic and 50 per cent primary austenite cools from the solidus temperature line EB, Fig. 44 (line SE, Fig. 45) pro-eutectoid cementite separates out from the primary (saturated) austenite and from the eutectic austenite. When the temperature has fallen to the transformation range, line PK, Fig. 44, this separation is complete, the alloy now consists of austenite of eutectoid composition, pro-eutectoid cementite and eutectic cementite. As the alloy cools through the transformation range the austenite, now of eutectoid composition, changes to pearlite. All transformations are now complete and our iron consists of 64 per cent pearlite, 10 per cent pro-eutectoid cementite and 26 per cent eutectic cementite.

The pearlite is made up of 55 per cent ferrite and 9 per cent cementite. If we collect the different classes of cementite present we will find that we have:

	Per cent
Pearlite Cementite	9.0
Pro-eutectoid Cementite	10.0
Eutectic Cementite	26.0

or a total of 45 per cent cementite, which is the cementite equivalent of 3.0 per cent carbon.

THE STRUCTURE OF HYPOEUTECTIC CAST IRON

Cast irons having a microstructure that corresponds to the theoretical requirements of the cementite-austenite diagram are difficult to find. Figs. 48 and 49 taken from Sauveur's text on metallurgy show the structure of a hypoeutectic cast iron (composition not stated). The light colored matrix is the austenite-cementite eutectic; the dark particles are crystallites of saturated austenite.

Figs. 50 and 51 show the structure of a commercial gray iron.

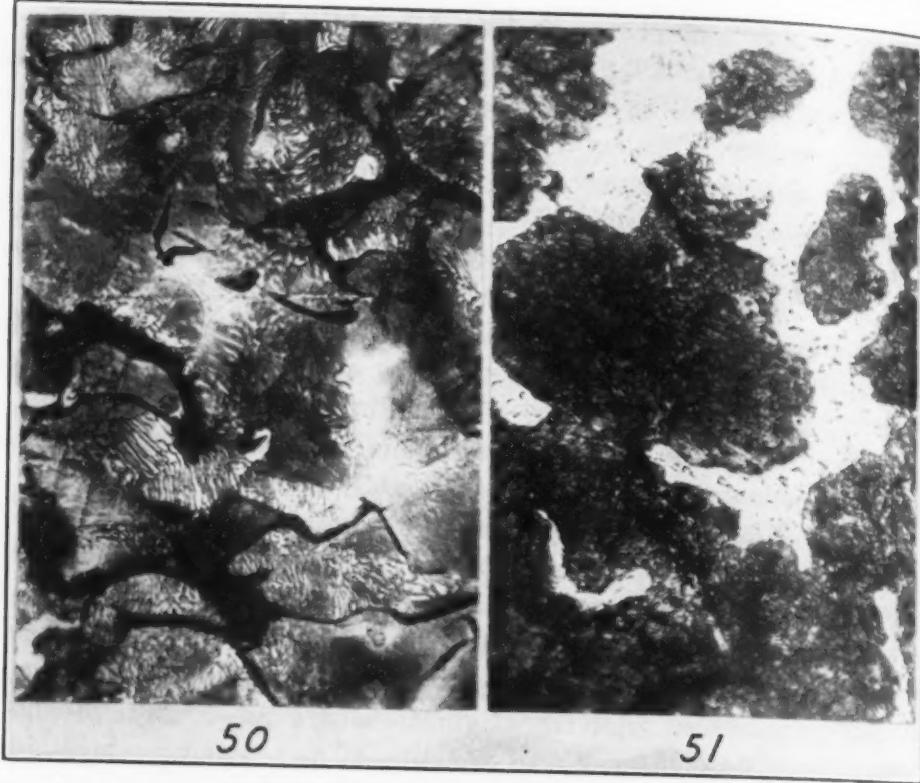


Fig. 50—Photomicrograph of Hypoeutectic Cast Iron Containing Laminated Pearlite. Etched with Alcoholic Nitric Acid. 100 x. Fig. 51—Photomicrograph of Hypoeutectic Cast Iron Containing Granular and Partially Laminated Pearlite. Etched with Alcoholic Nitric Acid. 500 x.

This iron had a combined carbon content of about 0.65 per cent. The balance of the carbon was in the form of graphite. Fig. 50 shows the pearlite in the matrix in a distinctly laminated form. Fig. 51 shows a matrix of granular pearlite. The white almost structureless areas in these two photomicrographs is the iron-carbon-phosphorus eutectic. Phosphorus and other impurities introduce complications into the structure of cast iron which will be discussed in a later chapter.

PROGRESS REPORT OF SUB-COMMITTEE ON THE MECHANISM OF CEMENTATION

THE Recommended Practice Committee approved, about a year ago, the appointment of a sub-committee to prepare a recommended practice on the mechanism of cementation. This subject was suggested by the Pittsburgh Chapter and was recommended because of the interest exhibited in the nitrogenizing of steel.

The personnel of the sub-committee on the Mechanism of Cementation is as follows:

Dr. V. N. Krivobok, chairman
W. B. Crowe
W. I. McInerney
Philip Emmett
P. C. Osterman
T. Holland Nelson

The sub-committee has had two meetings at which an extensive and comprehensive program has been outlined.

As it has been recognized for some time that nitrogen plays an important part in the carburizing of steel with carburizing compounds, the committee has planned to prepare a recommended practice covering cementation with nitrogen. It is true that nitrogen was generally considered deleterious when introduced into steel either through the energizers or by cyaniding, but it is now recognized that nitrogen is only injurious when the penetration is inter-granular.

The committee proposes to include the cyaniding process in a general way and lead up to the processes usually used when conducting the cementing process with nitrogen.

P. C. Osterman has been of valuable assistance to the committee in outlining its program and has given the committee considerable inspiration due to his close association in the extensive work of the American Gas Furnace Company with the nitrogenizing processes covered by the A. W. Machlet patents. The committee has also been strengthened by the appointment of T. Holland Nelson, who brings to the committee experience covering Dr. Fry's patents. Mr. Osterman and Mr. Nelson will prepare, for the sub-committee, a tentative practice covering the various processes for cementing with nitrogen. This tentative recommended practice will be used as a basis for the final work of the sub-committee.

There appears to be some confusion in regard to the proper term for this process. The committee is, however, designating this

treatment by "cementation with nitrogen." The Committee on Nomenclature will probably designate the proper term for the process.

After heat treating, finish machining, and then cementing with nitrogen, the products are extremely hard, but not unusually brittle, and in a very satisfactory condition to resist corrosion. The nitrogenized parts may be polished to give the appearance of highly polished nickel-plating, or if a colored surface is desired, the polished parts may be heated to the various temperatures usually employed in the tempering of carbon steel, depending upon the color desired, producing a complete range of beautiful temper colors, light straw, dark straw, brown, purple, blue, etc., yet, unlike the effect of such heating upon carbon steel, the hardness will not be reduced.

The usual methods for testing hardness are not suitable, due to the extreme hardness of the case, which has a tendency to spall when subjected to the present methods of hardness testing. However, the Herbert Pendulum and various scratch tests may be satisfactory for determining the hardness.

One outstanding advantage of the process is the absence of warping during the operation, which is due to the low temperatures used. The temperature used for cementing with nitrogen is well below the critical temperature range. Because of this low temperature, the steel is removed in a fairly clean condition. The process will be of use for the hardening of intricate parts that are difficult to carburize with compounds, and which warp or crack when quenched.

The committee is endeavoring to have some interesting information to present to the members of the A. S. S. T. on this subject within a few months.

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(Continued from Page 216)

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Reviews of Recent Patents

By

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Member of A. S. S. T.

1,611,798, Composition of Stainless Iron Alloy, Masaaki Yonezu, of Tokyo Fu, and Eitaro Endo, of Tokyo, Japan.

This patent relates to an improved stainless iron alloy containing chromium in percentages of 8 to 30 per cent, and in addition 1 to 10 per cent of vanadium, the remainder being iron. The normally high chromium steel hardens in air, cannot be annealed or made as soft as annealed carbon steel, is difficult to work in a lathe on account of its hardness and the fact that it cannot be annealed, and is difficult to bend or draw at atmospheric temperatures because of the tendency to crack due to the high chromium content. The addition of vanadium, however, in percentages of not less than 1 and not over 10 per cent, preferably in the proportion of 4 to 5 per cent, causes high chromium steel to lose its property at hardening not only in air, but also to lose the property of hardening when quenched from a high heat. The vanadium addition makes the high chromium steel soft without an annealing operation, rendering the same adaptable for work in a lathe and also flexible at atmospheric temperatures to permit bending and drawing. An alloy of the composition—chromium 13 per cent, vanadium 4 per cent and carbon 0.03 per cent, the remainder iron, has a Brinell hardness of 130 and can be bent through 180 degrees without cracking.

1,612,570, Making Iron Alloys, Leon Cammen, of New York City.

This patent describes the process of producing steel of extremely low carbon content and particularly silicon steel sheets for use in the electric field. The process is carried out in two or more stages under conditions which may produce a carbon content as low as 0.001 per cent. The first stage consists in over blowing the melt in a Bessemer converter until the iron begins to burn, then transferring preferably to an induction furnace capable of attaining a temperature of 2825 degrees Fahr. (1550 degrees Cent.) and in which there is no danger of contamination from carbon from an outside source. The metal is held in the induction furnace until the small percentage of carbon contained therein is substantially reduced by its deoxidizing action on the burned iron, after which the metal is deoxidized in the usual manner by the use of silicon, aluminum, or possibly manganese.

1,613,571, Process of Making Molybdenum Steel, Frederick M. Becket, of New York, N. Y., Assignor to Electro Metallurgical Company, a Corporation of West Virginia.

This patent describes the process of making molybdenum steel from native sulphide ores, without a preliminary roasting operation. The process is carried on under conditions in which the molybdenum content of the

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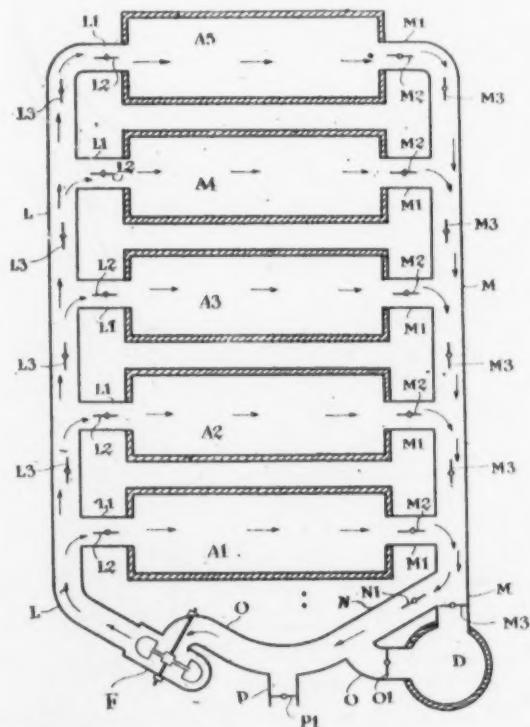
castings
in which

sulphide is recovered in a sufficiently high ratio to make the process commercially practical. As an example of the process, molybdenite (MoS_2) was added to a heat of steel in a basic lined electric furnace in such amounts that the molybdenite added was equal to 0.43 per cent by weight of the steel in the furnace, the addition was made after the first oxidizing slag had been removed, but prior to the attainment of strong reducing conditions, and was followed by furnace additions successively of washed metal, high-carbon ferromanganese, and low-carbon ferrochromium. Three hours after the addition of the molybdenite, the heat was poured and treated in the ladle with ferrosilicon. The finished steel had the following composition:

	Per cent
Carbon	0.37
Silicon	0.35
Manganese	0.81
Phosphorus	0.011
Sulphur	0.012
Chromium	1.12
Molybdenum	0.44

1,613,726, **Art of Annealing Metal**, Hugh W. Sanford, of Knoxville, Tennessee.

This patent describes a method and apparatus for annealing metal



castings and forgings, which comprises placing the metal in a soaking pit in which the atmosphere is excluded and then forcing a fluid medium, such

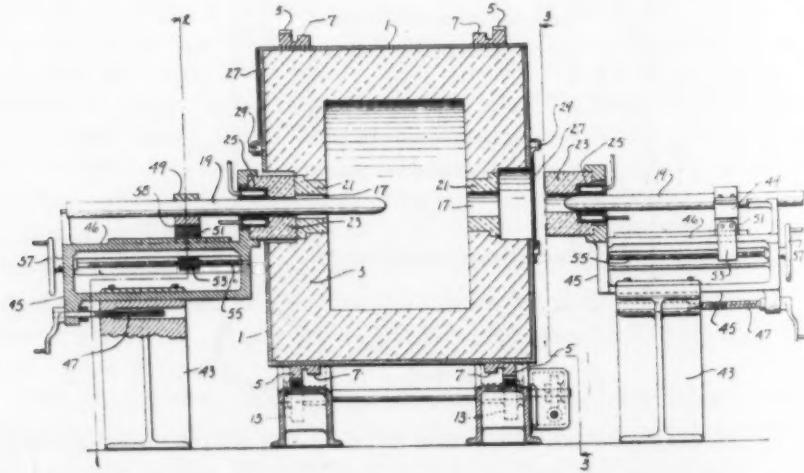
as ordinary air or other gas through the pit, the fluid medium being of a higher temperature than the temperature of the castings, whereby the castings are raised to an annealing temperature and then gradually reducing the temperature of the fluid medium to cool the castings. One form of the apparatus described consists of a group of annealing chambers A1, A2, A3, A4 and A5 arranged to permit the circulation of a fluid medium therethrough. D indicates a stove for controlling the temperature of the fluid medium and F a fan for forcing the circulation. Gates or dampers L2, L3 and M2 and M3 are arranged in the various conduits so as to permit the fluid medium to be directed in various ways through the chambers to accomplish the desired heating or cooling of the castings therein.

1,614,862, Method of Casting, Douglas T. Beatty, of Birmingham, Alabama, Assignor to Sand Spun Patents Corporation, of Wilmington, Delaware, a Corporation of Delaware.

This patent describes a process of preventing scuff, scoria and oxides and other materials of a lower specific gravity than the metal cast from depositing on the inner surface of a centrifugally cast hollow body, such as a pipe. The process comprises adding to the metal flowing into the mold a flux capable of combining with the impurities to produce a fluid slag which blankets the exposed surface of the metal in the rotating mold against oxidization by the air, and which evolves, when fused with silica, an inert gas which drives out the oxidizing gases in the mold and thereby establishes and maintains a nonoxidizing atmosphere. Suitable fluxing materials may comprise crude sodium carbonate, sodium chloride, or borax. Soda ash is preferable and is used in powdered form placed on the metal in the ladle just prior to casting. For a 12-foot length of 4 to 6-inch pipe, from $\frac{1}{2}$ to $1\frac{1}{2}$ pounds of soda ash are used.

1,615,109, Electric Furnace, James Robert Coe, of Waterbury, Connecticut, Assignor to the American Brass Company, of Waterbury, Connecticut, a Corporation of Connecticut.

This patent describes a rocking electric furnace 1, rocked by suitable



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gearing 5 and drawn to permit tilting or pourable carrier 49 to permit horizontal electrodes projecting cooling means and carried by shaft 47. To be brought into contact with the electrodes 19 and 20, admitting the fuel points for pouring.

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1,610,262,
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An alloy
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1,611,209.

This patent having a clamp end and a pair of relation to each receiving said brackets, said clamp being mounted upon lugs adapted to be mounted upon the sleeves by means for yielding and adjusting.

1,610,256

Describes
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gearing 5 and 13, from which the electrodes 19 may be conveniently withdrawn to permit the furnace to be moved from its base for the purpose of tilting or pouring its contents. The electrodes 19 are mounted in the movable carrier 49, which is controlled by hand wheel 57 and threaded shaft 55 to permit horizontal movement of the same relative to the furnace. The electrodes project through refractory plugs 23, provided with suitable water cooling means 25 for cooling the electrodes; the plugs 23 are mounted on and carried by a movable carriage 45 which is controlled by the threaded shaft 47. To insert the electrode in the furnace the carriage 45 is advanced by means of the threaded shaft 47 to bring the inner end of the plug 23 into contact with the bushing 21 of the furnace, and the electrode 19 is then advanced through the plug 23 by use of the threaded shaft 55. Electrodes 19 and plugs 23 are withdrawn by reversing this movement, permitting the furnace to be lifted from its base and transported to suitable points for pouring.

1,614,659, Foundry Sand, William Cureton, of Chicago, Illinois.

This patent describes an improvement in foundry sands, in which talc (magnesium silicate) is substituted as a binding agent for the clayey materials normally used in foundry sand. The silica sand and talc may be combined in a wide range of proportions depending on how strong a bond is desired in the foundry sand and the type of castings for which it is to be used. In addition to the talc and silica sand, a small amount of flint may be used.

1,610,262, Alloy, Hugh S. Cooper, Cleveland, Ohio, assignor to Kemet Laboratories Company, Inc., a Corporation of New York.

An alloy containing a preponderating amount of a metal having the properties of nickel and cobalt; from 1 per cent to 12 per cent each of tungsten and titanium; from 4 per cent to 10 per cent of aluminum; and from 2 per cent to 6 per cent of silicon.

1,611,209, Casting Machine, Louis E. Leyens, Vicksburg, Mass.

This patent describes a casting machine comprising a bottom plate having a clamping post projecting upwardly therefrom at each side of one end and a pair of hinge posts pivotally mounted upon the other end in spaced relation to each other, a top plate having a pair of eyes at one end for receiving said hinge posts, a clamping bracket pivotally mounted upon each of said clamping posts, a clamping device carried by each of said clamping brackets for adjustably engaging said top plate, a spacing sleeve rotatably mounted upon each of said clamping plates, said spacing sleeves having lugs adapted to be positioned to support said top plate, other spacing sleeves mounted upon said clamping posts and hinge posts, said last-mentioned spacing sleeves being slotted to permit their removal from said posts, spring means for yieldingly holding said last-mentioned spacing sleeves on said posts, and adjustable means for securing said sleeves on said posts.

1,610,256, Mold for Centrifugal Casting, Leon Cammen, New York, N. Y.

Describes a mold for centrifugal casting consisting of two parts disposed along the axis of rotation, of which parts the one against which the metal

of the casting is fed, has a smooth internal surface and the other part has projections of a shape suitable for the desired casting, and the former of the two projects into the latter and is connected thereto.

1,610,362, Process for the Treatment of Iron or Steel for Preventing Oxidation or Rusting, Thos. Watts Coslett, Birmingham, England.

This patent describes a process of the kind referred to for the treatment of iron or steel or articles composed or having a surface of iron or steel which consists in subjecting the same to the action of an aqueous solution of acid zinc phosphate and boric acid in the relative proportions of about two ounces of the phosphate and one and one-third ounces of the boric acid to one gallon of water, for the purpose specified.

1,611,020, Ingot Mold, Emil Gathmann, Baltimore, Md.

A patent describing a metallic mold provided with an ingot forming chamber open at top and bottom, in combination with a mold stool having a recess in communication with the bottom opening of the mold which recess is surrounded by an unbroken ledge and a ring of sealing material resting on said ledge and making contact with the side walls of the bottom opening of the mold.

1,611,804, Molding Machine, Henry Barkschat, Los Angeles, Calif., assignor to Marbelite Corporation of America, Los Angeles, Calif., a Corporation of Delaware.

In a machine of the character described, a pair of spaced and substantially axially aligned centrifuge units having mold taking chucks, a mold having a body portion of cast metal, and relatively resilient elements on the mold and interposed between the body portion and the jaws of the chucks.

1,606,927, Method of Operating Open-Hearth Furnaces, Waldemar Dysen, Tarrytown, N. Y.

This method of operating an open-hearth furnace consists in supplying fuel and combustion air alternately to opposite ends of the furnace, passing the waste gases alternately from each end of the furnace through a waste heat boiler to recover the heat energy therefrom and to cool the gases, mixing part of the gases so cooled with the gases leaving the outgoing end of the furnace so as to prevent the destruction of the port ends of the furnace.

1,607,681, Muffle Furnace, Leo W. Manion, Canton, Ohio.

In this furnace, a muffle is provided with a bottom wall of uniform thickness throughout its area having alternate similar ridges and depressions. The ridges are arranged to support burning racks and the depressions are arranged to receive charging forks.

1,610,567, Annealing of Sheet Steel, Henry S. Marsh and Ralf S. Cochran, Youngstown, Ohio.

The method herein described of annealing sheet steel which consists in heating the sheet material within a maximum time interval of seven minutes and while maintained in a nonoxidizing atmosphere to annealing temperature.

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THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies' Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALLOY STEELS

COBALT. Effect of Annealing Time and Temperature on Grain Size of 0.65 per cent Cobalt Steel (Glödgningstidens och glödningstemperaturrens inflytande pa kornstorleken hos ett stal av kohalt 0.65 vid olika slutbearbetningstemperaturer), G. Edstrand, Jernkonterets Annaler, vol. 811, no. 11, 1926, pp. 461-482, 29 figs. Connection of grain size and hardness or strength; methods of measuring hardness; microscopic study, etc. Bibliography.

COPPER STEEL. The Weather Resistance of Copper Steel (Die Witterungsbeständigkeit gekupferter Stähle), K. Daeves, Stahl und Eisen, vol. 46, no. 52, Dec. 30, 1926, pp. 1857-1863, 11 figs. Points out agreement in results of all tests on superiority of steel with copper content; importance in agriculture; experiences with railways; American large-scale tests, and confirmation by German tests; superiority of basic steel; theory of protective action; field of application of copper steels.

ALLOYS

HEAT-RESISTING. Heat Resisting Alloys. Metallurgist (Supp. to Engineer, vol. 142, no. 3703), Dec. 31, 1926, pp. 183-184, 4 figs. Abstract translated from Kruppsche Monatshefte, Oct. 1926, p. 154, giving advantages of such alloys over refractory materials; results of tests on alloys with trade names of Ferrotherm, Nichrotherm and Nialit; up to working temperature of 1000 degrees Cent., these alloys have wide sphere of usefulness, and castings weighing several tons have been made and proved satisfactory in service.

LUDWIG-SORET EFFECT. The Ludwig-Soret Phenomenon in Alloys (Le phénomène de Ludwig-Soret dans les alliages), M. Ballay. Académie des Sciences, Comptes rendus des séances, vol. 183, no. 15, Oct. 11, 1926, pp. 603-611. Experiments carried out which show that Ludwig-Soret effect (segregation

due to unequal heating of melts) is clearly established for liquid and for solid alloys.

POURING CAPACITY. Effect of Chemical Composition of Alloys on Pouring Capacity Influence de la composition chimique des alliages sur l'aptitude à l'obtention de pièces moulées (ou coulability), L. Guillet and A. Portevin. Académie des Sciences—Comptes Rendus, vol. 183, no. 16, Oct. 18, 1926, pp. 634-639. Authors distinguish between fluidity of alloy and its power of filling mold completely (flowability); latter has been determined at 550 and 450 degrees Cent., for alloys of tin with bismuth and with lead; "flowability" varies as continuous function of excess temperature of melt over that at which solidification starts; speed of solidification is specific property of alloy and must also be taken into account.

ALUMINUM

ELECTRODEPOSITION. Electrolytic Coating of Aluminum and Light Alloys, Adherence and Resistance to Corrosion in Salt Water (Sur quelques récouvrements électrolytiques de l'aluminium et des alliages légers, leur adhérence et leur résistance à la corrosion à l'eau de mer), J. Cournot and J. Bary. Académie des Sciences—Comptes Rendus, vol. 183, no. 19, Nov. 8, 1926, pp. 789-791. Electrolytic deposition of cadmium, cobalt and chromium on aluminum and duralumin, after preliminary copper coat; pickling, composition of electrolytic baths, etc.

ALUMINUM ALLOYS

ALUMINUM-BERYLLIUM. Improvement of Aluminum Alloys (Vergütbare Aluminiumlegierungen), W. Kroll. Metall u. Erz, vol. 23, no. 22, Nov. 2 issue, 1926, pp. 613-616. Substitution of beryllium for silicon; beryllium addition increases strength to small degree with metals of Lautal group; effect on duralumin is slight, but increase of strength with metals of Aludur type is con-

siderable. See also succeeding article by same author, pp. 616-618, 1 fig., on mechanical properties of binary aluminum-beryllium alloys.

ALUMINUM - CALCIUM - SILICON. The Aluminum-Silicon System (Ueber das System Aluminium-Kalzium-Silizium), G. Doan, Zeit. für Metallkunde, vol. 18, no. 11, Nov. 1926, pp. 350-355, 15 figs. Tests to determine possibility of improving aluminum by addition of calcium and silicon, in similar manner as by addition of magnesium and silicon; reactions in ternary system Al-Ca-Si; burning out of calcium in melting process; behavior of CaSi.

ALUMINUM - MAGNESIUM - CADMIUM. Study of Ternary Alloys (Contribution à l'étude des alliages ternaires), J. Valentini. Revue de Métallurgie, vol. 23, nos. 4 and 5, Apr. and May 1926, pp. 209-218 and 295-314, 27 figs. Experiments on alloys of aluminum, magnesium and cadmium; tests after various heat treatments; solidification; experiments are summed up in triangular diagram. See brief translated abstract in Brass World, vol. 22, no. 11, Nov. 1926, p. 361.

ALUMINUM-ZINC-TIN. Corrosion and Physical Properties of Some Alloys of Aluminum, Zinc and Tin, N. O. Taylor. Am. Inst. Min. & Met. Engrs.—Trans., no. 1632-E, Jan. 1927, 11 pp., 7 figs. Investigation to ascertain whether presence of tin in varying quantities would have appreciable influence in controlling action of swelling in cast aluminum-zinc, spiral pump rods used to circulate water in constant-temperature bath; large percentages of tin in alloys increased their ductility and their resistance to shock.

SAND-CAST. The Strasser Sand-Cast Zinc-Copper-Aluminum Alloys (Ueber die Strasserschen Aluminium-Gusslegierungen), M. v. Schwarz. Motorwagen, vol. 29, no. 29, Oct. 20, 1926, pp. 685-688, 4 figs. These alloys possess remarkable aging properties; with 80 per cent aluminum, alloy increases in tensile strength from 17,000 to 40,000 lbs. per sq. in., in 20 days aging, improvements in Brinell hardness, bending strength, and notched-bar impact strength are also secured; aging sets in immediately on fast cooling after casting; new alloys are said to be superior to silumin.

ALUMINUM BRONZE

CASTINGS. Tentative Specifications for Aluminum Bronze Castings. Foundry, vol. 54, no. 24, Dec. 15, 1926, supp. page, 1 fig. Foundry data sheet.

QUENCHING EFFECT OF. Transformations of Aluminum Bronzes (Sur les transformations subies par les bronzes d'aluminium), J. Bouldoires. Académie des Sciences—Comptes Rendus, vol. 183, no. 16, Oct. 18, 1926, pp. 660-661. Shows from experiments that velocity of cooling after annealing has great effect on resistance, maximum resistance occurring on quenching at 500 degrees Cent.

BLAST FURNACES

BLASTING. Blasting a Blast Furnace, D. F. North. Explosives Engr., vol. 4, no. 12, Dec. 1926, pp. 450-451, 4 figs. Preliminary preparation and right quantity of explosives properly placed were essential factors

requisite to successful shooting of large blast furnace at Pittsburgh, Pa., plant of American Steel & Wire Co.

DRYING OF BLAST. Silica Gel and the Drying of Furnace Blast. Metallurgist (Supp. to Engineer, vol. 142, no. 3703), Dec. 31, 1926, pp. 181-182. Review of chemical properties of silica gel; laws governing gas absorption by silica gel; advantages of using dry blast; describes drying installation, consisting of three absorbers which are vertical cylinders containing clusters of tubes, similar to surface condensers; active gel is fed by conveyor into one of the absorbers where it gives air, which has already passed through other two absorbers, its final drying. Process and installation were described by F. Krull in Zeit. des Vereines deutscher Ingenieure, July 3, 1926, p. 907.

EFFICIENCY INCREASE. Blast Furnace Efficiency Increases, R. H. Sweetser. Iron Trade Rev., vol. 80, no. 1, Jan. 6, 1927, pp. 23-25, 1 fig. 374 serviceable blast furnaces have greater per-stack capacity than ever before; direct causes of these increased outputs are: richer ore mixtures, better coke, higher blast temperature, and smoother operation.

ORE UNLOADERS AND SKIP HOISTS. Ore Unloaders, Blast Furnaces and Skip Hoists, D. W. Blakeslee. Iron & Steel Engr., vol. 3, no. 12, Dec. 1926, pp. 503-513, 28 figs. Bridgetype unloaders; stiff-leg unloaders; electric equipment employed; skip hoists for coal, coke and ashes.

SCRAP ADDITIONS. The Effect of Scrap Additions on Coke Consumption in Blast Furnaces (Der Kokerverbrauch beim Schrottzusatz im Hochofen), B. Osann, Stahl u. Eisen, vol. 46, no. 50, Dec. 16, 1926, pp. 1795-1796. Refers to article by E. Bormann in same journal, Dec. 10 and 17, 1925, and makes calculation of values of blast furnace gas composition, which agree well with those obtained by Bormann; it is shown that heavy drop in CO_2 content with scrap addition can only be attributed to decomposition of CO_2 by iron. See reference to Bormann's article in Eng. Index 1925, p. 78.

BRASS

ADDITIONAL MATERIAL FOR. An "Additional Material" for Brass. Metal Industry (Lond.), vol. 29, no. 25, Dec. 17, 1926, p. 582. Material, having trade name of Raffinat, introduced by G. Hirschland, Dusseldorf, Germany, for use in brass and gunmetal foundries; it combats difficulties attending use of scrap metals containing impurities, thus insuring production of perfect castings, even from scrap and swarf of inferior quality.

FOUNDING. "Non-Ferrous Foundry Practice," A. Logan. Foundry Trade J., vol. 34, nos. 538 and 539, Dec. 9 and 16, 1926, pp. 505-507, and 526-528, 7 figs. Deals mainly with metallurgical considerations of brass founding; solidification of nonferrous alloys; method of making alloy. Dec. 16. Casting temperature, manganese brass, aluminum bronzes; general considerations of nonferrous work.

BRASS FOUNDRIES

PYROMETER CONTROL. Temperature Determination in the Nonferrous Foundry.

Metal Industry (Lond.), 15, Oct. 1 and 338-339. Abstract before American Foundry, A. S. H. Casting of Nonferrous Thermocouple for Brass, A. A. Gruber. V. Nass, Oct. 8, 1926. Nonferrous Metal Tech.

BRONZE

STRUCTURE. (Der Aufbau des Bronzes), Zeit. für Metallkunde, 1926, pp. 347-348. Present knowledge of tin-zinc alloys, bimetallic study of structure.

CASE HARDENING

NITROGEN. Process Brought to Industrial Industries, 1926, p. 1013. Case on steel parts. Nitrogen into steel.

CAST IRON

ABRASION. Due to Gliding of Gusseisens bei der Schleifung, Lehmann. Gies. u. Sch., 21, 22 and 23, 1926, pp. 597-600, 62 figs. Refers to former work of cast iron; describes for this purpose the use of brake-shoe material of cast iron toward steel; inadequacy of present methods of determining abrasion resistance of grain testing of cast iron with phosphorus.

ELECTRIC ABRASION. Close Grain. Nov. 15, 1926, metal made in electric furnace readily at high temperature diversified; results two years by Latrobe, Pa.

NICKEL ADDITIONS. Nickel Into Cast Iron, vol. 17, no. 1, 1926. Cupola addition of nickel and contraction of iron.

PROBLEMS. Foundry, A. Allard, 34, no. 541, 1 fig. Rules for foundry; quality upon total carbon; points of much greater complexity is to be observed.

CASTING

CENTRIFUGAL CASTING. Steel, L. Camming—Preprint, 1927, 35 pp. 1 fig.

Metal Industry (Lond.), vol. 29, nos. 14 and 15, Oct. 1 and 8, 1926, pp. 309-313 and 338-339. Abstract of four papers presented before American Foundrymen's Assn., as follows: Oct. 1: Pyrometer Control in Brass Foundry, A. S. Hall; Use of Pyrometers in Casting of Nonferrous Metals, R. D. Bean; Thermocouple for Ladle Temperature of Brass, A. A. Grubb, L. H. Marshall and C. V. Nass, Oct. 8: Visual Judgment of Nonferrous Metal Temperature, R. R. Clarke.

BRONZE

STRUCTURE. The Structure of Bronze (Der Aufbau des Rotgusses), M. Hansen. Zeit. für Metallkunde, vol. 18, no. 11, Nov. 1926, pp. 347-349, 5 figs. Brief review of present knowledge of structure of copper-tin-zinc alloys, based on existing literature; study of structure, based on diagrams.

CASE HARDENING

NITROGEN. Nitrogen Case Hardening Process Brought to This Country. Automotive Industries, vol. 55, no. 25, Dec. 16, 1926, p. 1013. System of producing hard case on steel parts by causing diffusion of Nitrogen into surface layer of steel.

CAST IRON

ABRASION. The Abrasion of Cast Iron Due to Gliding Friction (Die Abnutzung des Gusseisens bei gleitender Reibung), O. H. Lehmann. Giesserei-Zeitung, vol. 23, nos. 21, 22 and 23, Nov. 1, 15 and Dec. 1, 1926, pp. 597-600, 623-627 and 654-656, 19 figs. Refers to former tests on abrasive resistance of cast iron; describes simple testing machine for this purpose; investigations made on brake-shoe material; behavior of gray cast iron toward steel, hard and soft castings; inadequacy of Brinell hardness test in determining abrasion of cast iron; importance of grain testing; abrasive resistance of gray cast iron with pure pearlitic structure; influence of phosphide eutectum. Bibliography.

ELECTRIC ALLOY. Electric Iron has Close Grain. Foundry, vol. 54, no. 22, Nov. 15, 1926, pp. 909-910, 4 figs. Alloy metal made in electric furnace has dense pearlitic structure and may be machined readily at high Brinell hardness; applications diversified; results of experiments for past two years by Vulcan Mold & Iron Co., Latrobe, Pa.

NICKEL ADDITION. The Introduction of Nickel Into Cast Iron. West. Machy. World, vol. 17, no. 12, Dec. 1926, pp. 548-549. Cupola additions of nickel; ladle additions; additions of nickel and chromium; fluidity and contraction; effect of nickel on strength of iron.

PROBLEMS. A Sceptic in the Iron Foundry, A. Allison. Foundry Trade Jl., vol. 34, no. 541, Dec. 30, 1926, pp. 567-568, 1 fig. Rules for pig iron; what happens at foundry; quality of cast iron turns largely upon total carbon contents and its condition; points out that cast iron calls for much greater care in control if higher quality is to be obtained.

CASTING

CENTRIFUGAL. Centrifugal Casting of Steel, L. Cammen. Am. Soc. for Steel Treating—Preprint, no. 4, for mtg. Jan. 20-21, 1927, 35 pp. 11 figs. Deals with centrifugal

tube casting and shows its present and prospective field of application and limitations, particularly where centrifugal tube casting comes into competition with piercing process; describes new art of centrifugal bar casting, affecting entire steel industry; its importance lies in its ability to produce metal of better quality at cost estimated to be from \$3.50 to \$8.50 per ton lower than present methods; explains mechanical and metallurgical features of process and machinery employed.

CASTINGS

ALLOY. Contraction in Alloy Casting, H. C. Dews. Foundry Trade Jl., vol. 34, nos. 540 and 541, Dec. 23, and 30, 1926, pp. 541-544 and 561. 7 figs. Discusses ways in which soundness of casting is related to volume changes brought about by change of temperature; deals with liquid, solid and pasty state of metals; what happens, when alloys freeze; location of contraction cavity; equal section not desirable; alloys with freezing ranges.

DEFECTIVE. RECLAMATION OF. The Reclamation of Defective Castings, C. W. Brett. Metal Industry (Lond.), vol. 29, no. 24, Dec. 10, 1926, pp. 561-562, 2 figs. Claims that it is now possible, on average basis, to reclaim at least 50 per cent of ordinary foundry scrap heap, and rapidly and economically restore it to full efficiency by one or other of half-dozen welding processes regularly employed; practical application of scientific methods; detection of welding imperfections.

CHROMIUM STEEL

EXHAUST VALVES, FOR. Chromium Steels and Cobalt Steels (Sur les aciers au chrome et au cobalt), F. M. Ostroga. Académie des Sciences—Comptes Rendus, vol. 183, no. 20, Nov. 15, 1926, pp. 882-885. Expansion and microstructure of chromium and cobalt steels used for exhaust valves in certain engines; facility of super-tempering them in air after heating to comparatively low temperature, etc.

COBALT

PHASE TRANSFORMATION OF. On a New Transformation of Cobalt and the Equilibrium Diagrams of Nickel-Cobalt and Iron-Cobalt, H. Masumoto. Tohoku Imperial University—Science Reports, vol. 15, no. 4, Oct. 1926, pp. 449-477, 21 figs. Measurements of electric conductivity, thermal expansion, heat evolution and magnetic change were made with several samples of cobalt and it was found that at certain temperature above 400 degrees Cent. discontinuous change of these properties, that is, transformation of phase, takes place; new transformation point of cobalt is greatly affected by other metals, especially iron; equilibrium diagrams for iron-cobalt and nickel-cobalt alloys were obtained. (In English.)

COPPER

BEHAVIOR UNDER STRESS. The Behavior of Industrial Copper under Stress as Indicated by Cold Working (Das Verhalten von Industriekupfer bei der Beanspruchung; erläutert bei Kaltbehandlung), E. Seidl and E. Schiebold. Zeit. für Metallkunde, vol. 18, nos. 8, 10 and 11, Aug., Oct. and Nov., 1926, pp. 242-246, 315-321, and 343-346, 50

figs. Results of research on cast work to determine conditions of inhomogeneity and its behavior under stress in cold state.

ROLLING AND HEAT TREATING. Copper and Brass Manufacture, W. R. Webster. *Iron Age*, vol. 118, no. 25, Dec. 16, 1926, pp. 1688-1690, 6 figs. Discussion of methods of rolling and heat treating for producing nonferrous wire sheets and other materials.

COPPER ALLOYS

COPPER-NICKEL. What Do We Know About Copper-Nickel Alloys? M. C. Corson. *Metal Industry* (N. Y.), vol. 24, no. 12, Dec. 1926, pp. 492-496, 5 figs. Comparison of properties of copper-base alloys containing varying quantities of nickel.

HIGH TEMPERATURE, FOR. Copper Alloys for High Temperatures, M. G. Corson. *Brass World*, vol. 22, no. 12, Dec. 1926, pp. 389-390, 1 fig. Additions of cobalt, chromium, silicides and beryllides has peculiar effects on hardness; diagram shows author's results of tests.

HOT FORGING. Effect of Hot Forging on Mechanical Properties of Alloys of Copper and of Aluminum (De l'influence du corroyage sur les propriétés mécaniques des alliages de cuivre et des alliages d'aluminium), M. Léon. *Académie des Sciences, Comptes Rendus*, vol. 183, no. 14, Oct. 4, 1926, pp. 541-544. Gives tables of impact and hardness tests before and after annealing of various types of brass, aluminum and alloys.

COPPER INDUSTRY

1926. Growth of Markets for Copper, H. D. Brophy. *Iron Age*, vol. 119, no. 1, Jan. 6, 1927, pp. 57-58. United States greatest consuming country as well as largest producer; new uses developed in recent years.

CORROSION

CHEMICAL-WORKS PUMPS. Some Cases of Corrosion in Chemical Works Pumps, H. Seymour. *Indus. Chemist*, vol. 11, no. 23, Dec. 1926, pp. 562-565, 4 figs. Corrosion in chemical-works pumps is due chiefly to action of acids, and when unsuitable materials have been used in construction of such pumps, parts made of non-resistant metal will enter into chemical combination with acid; great majority of corrosion phenomena is due to combined chemical and mechanical action on material.

IRON AND STEEL. The Corrosion and Rusting of Iron and Steel (Recherches sur la corrosion et l'enrouillement de l'acier et de la fonte), R. Girard. *Revue de Metallurgie*, vol. 23, nos. 6 and 7, June and July 1926, pp. 361-367 and 407-417, 33 figs.; also translated abstract in *Metallurgist* (Supp. to *Engineer*, vol. 142, no. 3698), Nov. 26, 1926, pp. 174-176, 5 figs. Results of experiments undertaken to study attack of ferrous metals by weak acids, show clear differences in conditions of rusting of steel and cast iron; results obtained from immersion in sulphuric acid, in carbonic acid, and in solution of sodium chloride; formation of compact adherent corrosion products suggests means for conservation of metals; it is thought that most of special corrosion-resisting alloys are of self-protective class.

OIL REFINERIES. Corrosion, An Economical Problem in the Refinery, H. F. Perkins. *Nat. Petroleum News*, vol. 18, no. 51, Dec. 22, 1926, pp. 73-79. Taking up refinery equipments by departments and by individual units, author shows where corrosion is most severe and what causes it; information as to metals which are practicable to use and which give highest resistance to corrosion. Paper read before Am. Petroleum Inst.

OIL REFINERIES. Corrosion in Petroleum Distillation, (Korrosionen in der Petroleumdestillation), H. Schmidt. *Petroleum*, vol. 22, no. 30, Oct. 20, 1926, pp. 1139-1140, 3 figs. Presents picture of conditions in Germany in regard to refinery corrosion; from all observations conclusion is drawn that up to date no practical corrosion-resistant material for distillation equipment has been found; presents table showing rate of destruction of metals and alloys by corrosion. See translation in *Nat. Petroleum News*, vol. 18, no. 49, Dec. 8, 1926, pp. 85-86.

OIL TANKS. Causes of Corrosion and Possible Remedies to be Applied, L. C. E. Bignell. *Nat. Petroleum News*, vol. 18, no. 52, Dec. 29, 1926, pp. 54-60, 1 fig. Deals with corrosion in steel tanks due to combination of sulphur with iron and steel.

WATER MAINS. Some Notes on the Corrosion of Water Mains, H. E. Bellamy. *Instn. Engrs. Australia—Quarterly Bul.*, vol. 3, no. 12, Oct. 31, 1926, pp. 319-334, 8 figs. Corrosion of cast iron, steel and wrought iron mains; tuberculation and electrolysis.

CUPOLAS

PROCESSES. Calculation of Cupola Processes and Practical Application (Die rechnerische Erfassung der Vorgänge im Kupolofen und ihre Verwertung für Bau und Betrieb), K. Pfeiffer. *Giesserei*, vol. 13, nos. 46, 47 and 48, Nov. 13, 20 and 27, 1926, pp. 877-887, 893-897 and 913-920, 9 figs. Part I: Heat balance; relation between reduction and exhaust-gas temperature; influence of height of cupola, etc. Part II: Reduction process; time function; derivation of a formula for duration of contact between CO_2 and glowing carbon; temperature losses. Part III: Principles of heat transmission; formula for melting-zone and exhaust-gas temperature. Part IV: Comparison of melting tests; application of results of investigation to cupola design and operation.

DROP FORGINGS

AMERICAN PRODUCTION METHODS. Impressions of American Forging Methods, F. W. Spencer. *Forging—Stamping—Heat Treating*, vol. 12, no. 12, Dec. 1926, pp. 475-477. Impressions of American methods of producing drop forgings which were gained in tour through number of commercial drop forge plants and drop forge departments connected with large automobile factories.

DURALUMIN

HARDNESS TESTING. Hardness Testing of Thin Duralumin Sheet, T. W. Downes. *Forging—Stamping—Heat Treating*, vol. 13, no. 1, Jan. 1927, pp. 18-23, 3 figs. Methods of hardness testing and relation between hardness and mechanical properties of heat treated, rolled duralumin sheet.

ELECTRIC FURNACES

ANNEALING. Annealing Furnaces (Annealing Furnace), H. F. Perkins. *Nat. Petroleum News*, vol. 18, no. 52, Dec. 29, 1926, pp. 1879, 3 figs. Steel works for with initial temperature required annealing degrees Cent. is current supply of usually 3000 m. 200 mm.; ad consists in exact maintenance simplicity of smoke and heat.

ANNEALING. Annealing Furnaces. Metallurgist, vol. 142, no. 3703, Dec. 1926, pp. 1879, 3 figs. Results of experiments on annealing of steel. Continuous annealing very mild steel of tests on furnace walls much higher first tried, which also reduced a translated from 1926, p. 1537.

BRASS FOUNDRY. Furnace in (L'utilisation fonderie des ferreux), A. des Electriciens, 1926, pp. 893-897. that have high electric furnaces for ferrous metals. describes lead furnaces have been applied States, including Ley, Rennerfels, furnaces of Brown Boveri, furnaces of A. Hauser; and naces; electric consumption compared with heating; a clearly on side.

CRUCIBLE FURNACES. Furnace (Uebersicht über schnell auswendig Widerstandsofen), Zeit. für angew. Chem., 45, Nov. 11, 1926. For heating resistance heating consisting of crucible special porcelain heating up to crucible is g with new heat.

FACTORIES. Manufacturing, N. Engr., vol. 11, no. 502, 11 figs. equipment in Electric Co. are and in furnace by heating; heat.

ELECTRIC FURNACES

ANNEALING. A New Type of Electric Annealing Furnace (Ein neuartiger elektrischer Tiehofen), E. F. Russ. *Stahl u. Eisen*, vol. 46, no. 52, Dec. 30, 1926, pp. 1878-1879, 3 figs. Furnace installed in Polish steel works for annealing of gun cylinders; with initial temperature of 20 degrees Cent., required annealing temperature of 850 degrees Cent. is reached in 2½ hr. with current supply of 198 kw-hr.; cylinders are usually 3000 mm. long with a diameter of 200 mm.; advantage of electric annealing consists in uniform heat distribution, in exact maintenance of desired temperature, simplicity of operation, and elimination of smoke and heat.

ANNEALING. Electric Annealing Furnaces. *Metallurgist* (Supp. to *Engineer*, vol. 142, no. 3703, Dec. 31, 1926, pp. 183-185). Results of experimental study of bright annealing of steel strip; deals with discontinuous annealing process, intended to soften very mild steel to maximum degree; results of tests on furnace designed by author, with walls much lighter and thinner than type first tried, while mass of subsidiary parts is also reduced as much as possible. Abstract translated from *Stahl u. Eisen*, Nov. 11, 1926, p. 1537.

BRASS FOUNDRIES. Use of the Electric Furnace in Nonferrous-Metal Foundries (L'utilisation des fours électriques dans la fonderie des alliages et des métaux non ferreux), A. Levasseur. *Société Française des Électriciens*—Bul., vol. 6, no. 60, Aug. 1926, pp. 893-913, 9 figs. Discusses causes that have hindered practical application of electric furnace in brass and other non-ferrous metal foundries in France, and describes leading types of furnaces which have been applied to this work in United States, including resistance furnaces of Bailey, Rennerfelt, Morgan and Hoskins; arc furnaces of Booth, Detroit, Rennerfelt, and Brown Boveri; low-frequency induction furnaces of Ajax-Wyatt and Röchling-Rodenhauser; and high frequency induction furnaces; electrothermal efficiency and power consumption of various types; yields are compared with those of older methods of heating; a net gain is considered to be clearly on side of electric furnace.

CRUCIBLE-HEATING. Simple Electric Furnace (Ueber einen selbst zu quickelnden, schnell auswechselbaren, elektrischen Tiegel-Widerstandsofen), A. Simon and G. Müller. *Zeit. für angewandte Chemie*, vol. 39, no. 45, Nov. 11, 1926, pp. 1377-1380, 6 figs. For heating crucibles, simple electric resistance heating unit has been designed, consisting of crucible, stand and jacket, all of special porcelain, which remains nonconducting up to 1300 degrees Cent. or more; crucible is grooved and can be easily wound with new heating coil when required.

FACTORIES. Electric Furnaces in Manufacturing, N. R. Stansel. *Iron & Steel Engr.*, vol. 3, no. 12, Dec. 1926, pp. 497-502, 11 figs. Details of electric furnace equipment in Schenectady Works of General Electric Co.; while equipment includes both arc and induction furnaces, resistor type furnace is by far most general in use; bulk heating; heat treatment processes; maintenance.

HARDENING. Hardening (Das Härteln), E. Schmidt. *Gewerbeleiss.*, vol. 105, no. 11, Nov. 1926, pp. 243-246, 5 figs. Details of electric salt bath hardening furnace of German General Electric Co. (A. E. G.), used for hardening of tools and other steel products, especially where large quantities have to be handled; also used for hardening of files, etc.

HEAT TREATING. Electric Rotary Furnace Automatically Operated, I. S. Wishoski. *Fuels & Furnaces*, vol. 5, no. 1, Jan. 1927, pp. 71-74 and 98, 5 figs. Furnace designed by Westinghouse Elec. & Mfg. Co. for heat treating of ball races; heat treating operation is entirely automatic from time charge is placed in pan on hearth until it is discharged into basket by quenching tank conveyor; very uniform results are obtained.

HEATING. Successful Electric Furnace for Heating Drill Steel, H. K. Fox. *West. Machy. World*, vol. 17, no. 12, Dec. 1926, pp. 536-537 and 546, 6 figs. Three O. D. Globar elements of 17 kw. each are provided running lengthwise through furnace, two units being placed in top of heat chamber above drills, and one being placed below drills in such manner that scale flaking off drills could not possibly come in contact with Globar element; one Globar unit is on continually; other two units are controlling temperature through on and off operation, with contactor.

HIGH FREQUENCY. High Frequency Furnaces (Einiges über Hochfrequenzöfen), J. Bronn. *Zeit. für Metallkunde*, vol. 18, no. 11, Nov. 1926, pp. 333-338, 10 figs.; also translated abstract in *Metallurgist* (Supp. to *Engineer*, vol. 142, no. 3703), Dec. 21, 1926, pp. 191-192. Attention is chiefly directed to experiments of Ribaud; deals with recent applications of high and medium frequency furnaces and their advantages over other types of furnaces in industrial use; details of performance of some of Ribaud's furnaces, which are being developed by Compagnie Electro-Thermique; refers to two distinct trends in American practice; advantages of induction furnaces, especially high frequency (ironless) furnaces.

HIGH FREQUENCY. The Use of High Frequency Induction Furnaces for Production of High Grade Steel (Ueber die Verwendung des Hochfrequenz-Induktionsöfen für die Edelstahlerzeugung), F. Körber, F. Wever and H. Neuhauss. *Stahl u. Eisen*, vol. 6, no. 47, Nov. 25, 1926, pp. 1641-1649, 18 figs. Decarburization and deoxidation; production of carbon-poor and carbon-rich steel in high frequency furnaces; possibilities of development.

IRON FOUNDRIES. Operating Experiences with an Electric Furnace in Foundry Practice (Betriebserfahrungen mit einem Elektroofen im Giessereibetrieb), R. Genwo. *Stahl u. Eisen*, vol. 46, no. 48, Dec. 2, 1926, pp. 1697-1701, 11 figs., partly on supp. plate. Arc furnace of Demag design, and its operating details of charge and product; comparison of costs of converter and electric furnace operation; melting of synthetic pig iron; gray cast iron and malleable castings in electric furnaces.

IRON AND STEEL INDUSTRY. Electric Furnaces in the Iron and Steel Industry, H. M. Boylston. *Fuels & Furnaces*,

vol. 5, no. 1, Jan. 1927, pp. 17-30, 15 figs. Various types of furnaces for steel making; principles of operation; basic and acid electric processes.

ROTATING ARC TYPE. Russians Use Rotating Arc Type Furnace, L. T. Aronoff. Foundry, vol. 54, no. 24, Dec. 15, 1926, pp. 980-983, 10 figs. Details of furnaces employing characteristics obtained by use of exciting coil to cause rotation of arc.

STEEL. Necessary Additions to Bhadravathi Works for the Production of Steel, M. B. T. Narayan. Mysore Engrs' Assn.—Bul., vol. 4, no. 3, July, Aug. and Sept. 1926, pp. 12-22. Discusses possibility of producing cheaper or better pig iron, cheaper and better casting, such as are usually in demand all over India; advantages gained by electric heating; requirements of electric furnace in production of ordinary steel, high-quality crucible steel, high-grade and malleable castings; details of Rochling-Rodenhauser furnace.

TRANSFORMERS. Notes on Electric Furnaces (Notes sur les fours d'electrochimie) Bergeon and Bunet. Societe Francaise des Electriciens—Bul., vol. 6, no. 60, Aug. 1926, pp. 873-892, 3 figs. Deals with primary and secondary power factor of furnace transformers, between which there may be difference of 10 per cent, and gives methods for determining this; all methods assume sinusoidal wave form and are therefore not applicable to arc furnaces; various methods are compared by calculations on four transformers. See brief translated abstract in Sci. Abstracts (Section B), vol. 29, no. 348, Dec. 25, 1926, pp. 543-544.

ZINC PRODUCTION, FOR. New Electric Furnace for Production of Zinc (Nouveau four électrique pour la fabrication du zinc), Jl. du Four Electrique, vol. 35, no. 17, Dec. 1, 1926, pp. 259-261, 5 figs. Details of Sabathier process; furnace is equipped with one or more tubular electrodes in parallel or series, employed as muffle; operation of furnace; comparison with other processes.

ELECTRIC WELDING, ARC

GAS-ELECTRIC CAR. Gas-Electric Welding Car. Am. Mach., vol. 66, no. 1, Jan. 6, 1927, p. 35, 1 fig. Electric Arc Cutting and Welding Co., Newark, N. J., has brought out gas-electric-drive, self-propelled welding-car; consists of standard gas engine mounted in standard truck car; generator provides both alternating and direct current for arc welding.

MANUFACTURING PROCESS, AS. Arc Welding as a Manufacturing Process, A. G. Bissell. Am. Mach., vol. 65, no. 27, Dec. 30, 1926, pp. 1057-1059, 3 figs. Methods to be followed in introducing welding process in any industry.

OXIDATION OF ARC CRATER. Oxidation of the Arc Crater, P. Alexander. Am. Welding Soc.—Jl., vol. 5, no. 12, Dec. 1926, pp. 11-14. Discusses oxidation and nitro-genation of molten iron in crater of welding arc; study of relation of oxidation of surface of crater to number of gas pockets in solidifying metal.

QUASI-ARC. "Quasi-Arc" Electric Welding Used to Repair Princess Bridge, Mel-

bourne. Indian Eng., vol. 80, no. 18, Oct. 30, 1926, p. 248, 3 figs. Particulars of repair work carried out using quasi-arc electrodes.

RAILS. Renewing Battered Rail Ends by Arc Welding, M. Whine and A. V. Thompson. Gen. Elec. Rev., vol. 29, no. 12, Dec. 1926, pp. 880-881, 3 figs. Results of tests by Southern Pacific R. R. Co., making use of 2 gas-engine-driven sets.

STRUCTURAL STEEL. Structural Steel Session. Am. Welding Soc.—Jl., vol. 5, no. 12, Dec. 1926, pp. 24-32. Discussion of paper by A. M. Candy on Comparative Tests on Arc and Riveted Structural Members.

STRUCTURAL STEEL. Tests of Arc Welded Structural Steel, A. M. Candy. Eng. Jl., vol. 9, no. 12, Dec. 1926, pp. 518-522, 15 figs. Test specimens were all welded with various members located in same position and manner as would be required if they were actually part of building structure.

ELECTRIC WELDING, RESIST-ANCE

BUTT. Butt Welding Long Seams. Welding Engr., vol. 11, no. 12, Dec. 1926, pp. 31-32, 2 figs. Application of resistance butt welding to long seams makes possible rapid production of welded steel automobile bodies.

FORGING

BOLT AND NUT. The Development of Bolt and Nut Forging, E. J. Wiley. Machy. (Lond.), vol. 29, no. 742, Dec. 30, 1926, pp. 430-434, 12 figs. History of development; Oliver Machine; vertical-bolt press; rotary rivet machine; plunger-type tools; radial hammer machines; heading difficulties; use of bunting tools; reduction in bolt head sizes.

CAR AXLE RECLAMATION. Reclaiming Car Axles in Forging Machines. Machy. (N. Y.), vol. 33, no. 5, Jan. 1927, pp. 383-384, 2 figs. Reclamation of car axles up to annealing process can be accomplished in single machine built by Ajax Mfg. Co., Cleveland, O.; machine is new model 6-in. twin-gearred upsetting forging machine, provided with increased power for die mechanism.

CAR AXLE RECLAMATION. Reclaiming Scrap Car Axles. Forging-Stamping-Heat Treating, vol. 13, no. 1, Jan. 1927, pp. 24-25, 2 figs. Best practices in reclaiming processes consist of (1) disposing of old end collars by drawing down on steam hammer or turning off in lathe; (2) lengthening axle between journals so that worn fillets will clean up when machined, either by drawing out under hammer or swaging in bulldozer or upsetting forging machine; (3) forming new end collars and shortening overall length to that of next smaller size axle in either upsetting forging machine or bulldozer.

FORGINGS

BRASS. Brass Forgings, O. J. Berger. Machy. (Lond.), vol. 29, no. 742, Dec. 30, 1926, pp. 414-415. Finish and strength of forgings; composition of material; equipment for forging shop; preparing forging blank; dies for hot-pressed parts; and for drop and steam hammers; limits on forging dimensions; importance of correct heating.

FUEL ECON.

STEEL INDUSTRY
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FUEL ECONOMY

STEEL INDUSTRY. Fuel Economy in the Steel Industry, H. A. Bassett. Blast furnace & Steel Plant, vol. 14, no. 12, Dec. 1926, pp. 502-504 and 512. Possibilities of fuel economy in iron and steel industry; American and German practice compared; output and labor saving first in American plants. Paper presented at Int. Conference on Bituminous Coal.

FURNACES, ANNEALING

OIL-BURNING. Oil-Burning Annealing Furnaces, C. C. Hermann. Machy. (N. Y.), vol. 33, no. 5, Jan. 1927, pp. 357-358, 3 figs. Use of oil as heating medium in annealing furnaces employed in malleable-iron industry; details of oil burner; packing castings in annealing pots; annealing operation.

FURNACES, GAS

BRASS-MELTING. Gas Furnaces in Melting Brass. Gas Age-Rec., vol. 58, no. 24, Dec. 11, 1926, pp. 837-838. Comparison between gas- and coal-fired furnaces, showing comparative cost and performance.

BRASS-MELTING. Performance of Gas Fuel in White Brass Furnaces. Gas Age-Rec., vol. 58, no. 26, Dec. 25, 1926, pp. 917-918. Stewart Die Casting Corp. is melting 30,000,000 lb. soft metal per year with gas; production is increasing; temperature control is simplified and there is no investment in storage and handling equipment.

FURNACES, HEAT TREATING

PRODUCE GAS-FIRED. Tube Mill Furnace Fired with Raw Producer Gas, W. N. Robinson. Fuels & Furnaces, vol. 5, no. 1, Jan. 1927, pp. 87-90, 4 figs. Furnaces for annealing, normalizing, hardening and tempering of carbon and alloy-steel tubes at Ohio Seamless Tube Co., are being fired with producer gas; exceptional uniformity of heating secured and temperature and atmosphere readily controlled.

FURNACES, HEATING

INGOT HEATING. Thermal Efficiency of Ingot Heating Furnaces (Wärmeleistung von Stossöfen), W. Tafel and H. Grünn. Stahl u. Eisen, vol. 46, no. 49, Dec. 9, 1926, pp. 1750-1752. Determination of heat transmission coefficient between gases and ingots; application of results.

FURNACES, INDUSTRIAL

DESIGN. Industrial Furnaces, C. Longecker. Iron Trade Rev., vol. 79, nos. 10, 14, 16, 18, 20, 22, 24 and 26, Sept. 2, 30, Oct. 14, 28, Nov. 11, 25, Dec. 9 and 23, 1926, pp. 568-571, 843-845, 981-983, 1106-1108, 1231-1233, 1355-1357 and 1361, 1496-1498 and 1625-1627, 35 figs. Treatise on design, construction and function of modern melting, heating and treating units; intermediate or heating furnaces; reheating or finishing furnaces.

DESIGN. Practical Industrial Furnace Design, M. H. Mawhinney. Forging-Stamping-Heat Treating, vol. 13, no. 1, Jan. 1927, pp. 2-8 and 11, 3 figs. Discusses latest methods of utilizing various fuels for industrial furnaces; comparative costs of fuels.

EUROPEAN. Recent European Furnace Developments. Fuels & Furnaces, vol. 5, no.

1, Jan. 1927, pp. 51-55, 16 figs. Improvements in industrial furnaces and methods of operation; includes continuous furnaces for heating steel blooms and billets, recuperative forge furnace with integral gas producer; forge furnace with recuperative semi-gas firing; enameling furnace; bright annealing furnace, etc. Abstract translated from V. D. I. Zeit.

FURNACES, METALLURGICAL

WASTE-HEAT UTILIZATION. Utilizing the Heat of Flue Gases From Metallurgical Furnaces (Tillgödögröende av värmel i avgående rökgas från nagra metallurgiska ugnar), B. Afzelius. Jernkontorets Annaler, vol. 811, May 29, 1926, pp. 22-85, 32 figs. Heat balance and available waste heat from furnaces; various uses of waste heat, for starting up furnaces, etc.; design of furnaces.

HARDNESS

BRINELL TEST. Brinell Test Depth Indicator. Engineering, vol. 122, no. 3180, Dec. 24, 1926, pp. 784-785, 3 figs. Instrument brought out by A. J. Amsler & Co., Switzerland, known as imprint depth indicator, constituting ball carrier and depth measurer combined.

BRINELL TEST. Standardizing the Brinell Hardness Test, H. M. German. Am. Soc. for Steel Treating, vol. 11, no. 1, Jan. 1927, pp. 54-61 and (discussion) 61-72, 2 figs. Points out defects in different types of Brinell machines and describes new design which will overcome these defects and eliminate personal factor of operator, thereby standardizing Brinell hardness test.

TESTING. Hardness Tests Research. Machy. (Lond.), vol. 29, no. 742, Dec. 30, 1926, pp. 424-426, 1 fig. Report on diamond-cone indentation hardness tests; tests with various cones; comparison of results with other hardness tests; investigation shows that diamond cones can be used for accurate and reliable indentation tests on hard materials, and when results are corrected for adhesion or friction, direct comparison can be made with steel cone or ball test results on softer materials. (Abstract.) Paper read before Instn. Mech. Engrs.

TESTING. Methods of Hardness Testing. Am. Mach., vol. 65, no. 26, Dec. 23, 1926, p. 1041, 3 figs. Scleroscope and its use; reference-book sheet.

TESTING. The Measurement of Hardness. Metallurgist (Supp. to Engineer, vol. 142, no. 3703), Dec. 31, 1926, pp. 188-189, 4 figs. Review of papers by Esnault-Pelterie and Nicoll in Revue de Metallurgie, vol. 23, Oct. 1926; former reviews different methods of measuring hardness, and points out disadvantages of Brinell test; latter deals with Rockwell test; refers also to article by Le Rolland in same journal, describing pendulum machine; these three papers show great diversity of opinion which exists as to best methods of measuring hardness.

HEATING, GAS

INDUSTRIAL. The Use of Gas in the Typewriter Industry, R. L. Manier. Gas Age-Rec., vol. 58, no. 26, Dec. 25, 1926, pp. 907-908, 3 figs. Points out that use of gas has proved its worth in plant of L. C. Smith Typewriter by producing highest quality

work at lowest possible cost consistent with such quality; details of tool treating equipment; gas-fired Japan ovens; carburizing machine, etc.

IMPACT TESTING

NOTCHED-BAR TESTS. Law of Similarity in Connection with the Notched-Bar Test (Das Ähnlichkeitgesetz bei der Kerbschlagprobe), R. Mailänder. *Stahl u. Eisen*, vol. 46, no. 49, Dec. 9, 1926, pp. 1752-1757, 9 figs. Review of results obtained by Striebeck, Schüle und Moser; tests on three different steels to determine influence of notch diameter and size of test piece.

IRON

DIRECT PRODUCTION. The Ironfounder and Direct Iron Production, C. Gilles. *Foundry Trade Jl.*, vol. 34, no. 541, Dec. 30, 1926, pp. 363-566, 2 figs. Deals with Corsalli process, whereby low-carbon iron (especially iron and steel scrap) should be melted, added iron alloys being protected at same time by briquetting and encrusting them; casting properties of Corsalli iron; direct process. Paper read before German Foundrymen's Society.

RECRYSTALLIZATION. The Change of Crystallite Orientation with Recrystallization in Iron (Die Änderung der Kristalliten-Orientierung bei der Rekristallisation im Eisen), G. Tammann and H. H. Meyer. *Zeit. für Metallkunde*, vol. 18, no. 11, Nov. 1926, pp. 339-342, 3 figs. Crystallite orientation in low-carbon steel and chill castings containing silicon; crystallite orientation in rolled electrolytic iron and electrolytic iron wire after recrystallization; process of rolling iron.

STAINLESS. The Tensile Properties of Stainless Iron and Other Alloys at Elevated Temperatures, P. G. McVetty and N. L. Mochel. *Am. Soc. for Steel Treating*, vol. 11, no. 1, Jan. 1927, pp. 73-93 and (discussion) 93-100 and 169, 18 figs. Discusses tensile properties of annealed stainless iron and hot-rolled Monel metal at temperatures up to 500 degrees Cent., and compared them with similar properties of seven other materials; presents charts showing that comparison of normal temperature tensile properties of materials does not indicate their relative value at elevated working temperatures; gives data to show effects of sustained tension loading at high temperature upon tensile properties of materials at that temperature; requirements of apparatus for these tests; describes modified form of Martens extensometer which combines simplicity and ease of operation with high degree of precision of measurements. Bibliography.

IRON ALLOYS

BRINELL BALLS, FOR. Iron-Carbon-Vanadium Alloy for Brinell Balls, G. W. Quick and L. Jordan. *Am. Soc. for Steel Treating*—Preprint, no. 3, for mtg. Jan. 20, 21, 1927, 22 pp., 5 figs. Special alloy of about 2.9 per cent carbon and 13 per cent vanadium has been experimentally used; for Brinell balls in testing of steels of such hardnesses as cause ordinary Brinell balls to deform both elastically and plastically; these special balls, heat treated, work-hardened, and tested against steels of approximately 700 Brinell, flattened about $\frac{1}{2}$ as much as Hultgren balls and $\frac{1}{5}$ as much as ordin-

ary Brinell balls; opinion that hardness obtainable in plain carbon steel by combined heat treatment and cold work is maximum hardness to be secured by such treatments is shown to be untrue.

IRON-CARBON-OXYGEN. Equilibrium Between Iron, Carbon and Oxygen: Reduction of Iron Ores, Cementation and Gas Occlusion of Iron and Steel, K. Iwase. *Tohoku Imperial Univ.—Science Reports*, vol. 15, no. 4, Oct. 1926, pp. 511-529, 6 figs. Shows how equilibrium of this system is determined and how mechanism of reduction of iron ores by carbon and gas occlusion may be explained. (In English.)

IRON CASTINGS

COST FIXING. Fixing Costs for Gray Iron Castings, H. P. Parrock. *Iron Age*, vol. 118, nos. 25 and 27, Dec. 16 and 30, 1926, pp. 1681-1683 and 1815-1816, 2 figs. Dec. 16: Analysis of elements in jobbing foundry, for varying production; taking adequate profit into consideration. Dec. 30: Comparison of figuring methods of 5 foundries; derivation of estimating formula for pricing.

IRON METALLURGY

PROGRESS, 1926. Ferrous Metallurgy Advances, H. M. Boylston. *Iron Age*, vol. 119, no. 1, Jan. 6, 1927, pp. 44-49. Strides made in heat treatment and metallography; progress in blast furnace, steel making and foundry practice.

IRON, PIG

MAYARI. Some Uses of Mayari Pig Iron. West. Machy. World, vol. 17, no. 12, Dec. 1926, pp. 549 and 566. By using proper grade of Mayari iron, it is possible to produce either gray iron, chilled iron, white iron, or high-test castings; it is particularly well adapted to making white-iron castings; gives example of composition, strength, and hardness of typical motor casting made with addition of 10 per cent Mayari iron.

MAGNESIUM

PROPERTIES. Notes on Magnesium and its Alloys, W. R. D. Jones. *Royal Aeronautical Soc.—Jl.*, vol. 30, no. 192, Dec. 1926, pp. 743-761 and (discussion) 761-771; also abstract in *Am. Metal Market*, vol. 33, No. 242, Dec. 18, 1926, pp. 8-11 and 26. Review of developments; presents table of physical properties of magnesium which are compared with those of other pure commercial metals; in cast state magnesium is stronger than aluminum but is weaker than other metals; properties are greatly improved by forging, becoming very much superior to those of forged aluminum; alloys of magnesium; comparison of steel and duralumin; with elektron; zinc-magnesium, aluminum-magnesium, copper-magnesium alloys; Dow metal; founding of magnesium and its alloys.

MANGANESE STEEL

ELECTRIC SMELTING FURNACES, FOR. Rolled Manganese Steel Used in Large Electric Smelting Furnace. *Iron Age*, vol. 118, no. 27, Dec. 30, 1926, p. 1822, 1 fig. Outstanding characteristics of this steel, which contains 1 to 1.30 per cent carbon and 11 to

14 per cent manganese; shearing strength, impact and abrasion.

MALLEABLE

BLACK-HEART MALLEABLE. Discuss Malleable Jl., vol. 34, 1, 510-512. Discussion on manufacture of malleable cast early beginning of black fracture treatment; British pig iron heat treatment.

GRAPHITIZATION Cast Iron and Graphitization, T. Kikuchi. *Iron Age*, vol. 118, nos. 534, 535, Dec. 2, 1926, 477-479, 14 figs. Cast iron into temperature of graphitization; effect of graphitization; electrical tests. Effect of graphitization; of Tohoku Iron.

MALLEABLE ANNEALING Malleable Iron in Furnaces, vol. 5, 90, 5 figs. 195 feet long; anneals 25 tons gas-fired and temperature control.

ANNEALING heart Malleable Iron Trade Jl., vol. 34, pp. 550-554, annealed, over-annealed, over-annealed bars; heated bars;

METALLURGY WASHINGTON A Review of the Washingtonmann. Am. print, for metal up-to-date metallurgy; material; metallurgy; drill industry.

METALS GAS OCC Gases by Metal Solid States Univ.—Science 1926, pp. 51-52. Hydrogen, nitrates and under one various temperature state are measured, and the according to the as temperature and CO_2 .

MELTING industry (London)

14 per cent manganese are high tensile and shearing strength, resistance to wear by impact and abrasion, and nonmagnetic properties.

MALLEABLE CASTINGS

BLACK-HEART. Lancashire Foundrymen Discuss Malleable Castings. *Foundry Trade Jl.*, vol. 34, no. 538, Dec. 9, 1926, pp. 510-512. Discussion of paper by A. E. Peace on manufacture and properties of black-heart malleable cast iron; defects of black-heart; early beginnings; molding troubles; origin of black fracture; effect of subsequent heat treatment; comparison of American and British pig iron; obtaining low carbon; heat treatment limitations.

GRAPHITIZATION. On the Malleable Cast Iron and the Mechanism of its Graphitization, T. Kikuta. *Foundry Trade Jl.*, vol. 34, nos. 534, 536 and 537, Nov. 11, 25 and Dec. 2, 1926, pp. 409-412, 464-466 and 477-479, 14 figs. Graphitization of white cast iron into malleable cast iron; effect of temperature on first and second stages of graphitization; effect of thickness of casting; effect of chemical composition on graphitization; effect of phosphorus; practical tests. Extracted from *Science Reports of Tohoku Imperial Univ.*, Japan.

MALLEABLE IRON

ANNEALING. Continuous Annealing of Malleable Iron, G. Blakney. *Fuels & Furnaces*, vol. 5, no. 1, Jan. 1927, pp. 79-82 and 90, 5 figs. Continuous malleable kiln is 195 feet long, operating on 120-hour cycle, anneals 25 tons of castings per day; kiln is gas-fired and is equipped with automatic temperature control.

ANNEALING. Notes on Annealing Black-heart Malleable, C. Kluijtmans. *Foundry Trade Jl.*, vol. 34, no. 540, Dec. 23, 1926, pp. 550-554, 19 figs. Overheated, under-annealed, over-annealed and burnt iron; metallurgical reactions; annealing defects; overheated bars; cooling range.

METALLURGY

WASHINGTON - BALTIMORE DISTRICT. A Review of the Metallurgical Activities of the Washington-Baltimore District, E. Gathmann. *Am. Soc. for Steel Treating*—Preprint, for mtg. Jan. 20-21, 1927, no. 1, 23 pp. General review of historical and up-to-date metallurgical activities in territory; manufacture of corrosion-resisting material; manufacture of bottle caps, electric drill industry; National Bureau of Standards.

METALS

GAS OCCLUSION BY. Occlusion of Gases by Metals and Alloys in Liquid and Solid States, K. Iwase. *Tohoku Imperial Univ.*—*Science Reports*, vol. 15, no. 4, Oct. 1926, pp. 531-566, 35 figs. Solubilities of hydrogen, nitrogen, CO and CO₂ in pure metals and in alloys have been determined under one atmospheric pressure and at various temperatures; solubilities in liquid state are much greater than those in solid state, and temperature coefficients differ according to these states; solubilities increase as temperature rises, except in case of CO and CO₂. (In English.)

MELTING. Metal Melting. *Metal Industry (Lond.)*, vol. 29, no. 26, Dec. 17,

1926, pp. 580-582. Review of papers presented at joint meeting of Staffordshire Iron & Steel Inst., Birmingham Met. Soc. and Inst. of Metals on methods and processes.

PLASTICITY. On the Plasticity of Metals, H. Shoji. *Tohoku Imperial Univ.*—*Science Reports*, vol. 15, no. 4, Oct. 1926, pp. 427-442, 26 figs. Definition of plasticity of metals; apparatus for experiments; results of experiments at room temperatures; new definition is proposed for plasticity; plasticity of ductile metals decreases more rapidly with period of strain as compared with other metals. (In English.)

PLASTICITY. On the Plasticity of Metals at High Temperatures, H. Shoji and Y. Mashiyama. *Tohoku Imperial Univ.*—*Science Reports*, vol. 15, no. 4, Oct. 1926, pp. 443-447, 6 figs. Plasticity of lead, tin and cadmium have been measured at various temperatures; plasticity increases rapidly with rise of temperature and becomes very large at their melting points; elastic limit or yielding point of metals decreases with rise of temperature and becomes zero at melting points. (In English.)

X-RAY EXAMINATION. Examining Metals by Means of X-Rays (Genomlysning av metaller medelst röntgenstrålar), J. Härden. *Teknisk Tidskrift (Allmänna Ardelningen)*, vol. 56, no. 37, Sept. 11, 1926, pp. 337-340, 8 figs. Methods of examining semi-finished products such as nickel, chromium and tungsten steels for structural and other defects, and most recent X-ray tubes used.

MONEL METAL

WIRE PRODUCTION, FOR. Working Monel Metal from Two-Ton Ingot to Hair-Fine Wire. *Wire*, vol. 2, no. 1, Jan. 1927, pp. 15 and 32, 3 figs. Method of producing wire, fourteen ten-thousandths of an inch in diameter from two-ton Monel metal or nickel ingots measuring 13 inches square by 5 feet in length.

NICKEL STEEL

ELECTRICAL RESISTANCE. Dependence of the Electrical Resistance of Nickel Steel on Composition, Temperature, and Heat Treatment, (Ueber die Abhängigkeit des elektrischen Widerstandes der Nickelstähle von Zusammensetzung, Temperatur und Wärmebehandlung), F. Ribbeck. *Zeit. für Physik*, vol. 38, no. 9-10, Aug. 31, 1926, pp. 772-787, 4 figs. After quoting figures showing lack of agreement obtained by other workers for nickel steels, author describes method of determining resistance and gives results for iron as pure as possible; various proportions of nickel and carbon for range of temperature from about 20 to 300 degrees Cent.; some steels showed "induced effect" (Anlasserscheinung), possessing lower resistance when cooled from 300 degrees Cent. to given temperature than when heated to that temperature; in all cases resistance increases with rise in temperature. See brief translated abstract in *Chem. & Industry*, vol. 45, no. 48, Nov. 26, 1926, pp. 949-950.

NONFERROUS METALS

PROGRESS, 1926. Progress in Nonferrous Metals, W. M. Corse. *Iron Age*, vol. 119, no. 1, Jan. 6, 1927, pp. 53-56. Review of developments; copper still in lead; revival in nickel; tin substitutes increase; interest in aluminum bronzes.

RIVETING

WELDING VS. The Riveting and Welding Processes. *Machy.* (N. Y.), vol. 33, no. 5, Jan. 1927, pp. 350-351. Welding as applied to boilers; ductility and fatigue resistance; machine-driven rivets; future developments.

ROLLING MILLS

AUXILIARY MOTORS. New and Interesting Auxiliary Motor and Control Applications. P. McShane. *Iron & Steel Engr.*, vol. 3, no. 12, Dec. 1926, pp. 514-518, 18 figs. As example of what can be done with auxiliary control toward reducing cost by elimination of delays and reduced repair cost, author describes 40-inch blooming mill auxiliary installation; electromagnetic controller; blooming mill shear for 35-inch mill.

BRASS. The Dallas Brass Rolling Mill. *Metal Industry*, (N. Y.), vol. 24, no. 12, Dec. 1926, pp. 489-491, 4 figs. Details of sheet-brass rolling mill in Chicago, Ill.; raw material is melted in Ajax-Wyatt electric furnaces of induction type and formed into bars.

HOT ROLLING. Recent Improvements in Hot Rolling Mills (Les récents perfectionnements apportés aux laminoirs à chaud), P. Brenier. *Technique Moderne*, vol. 18, no. 21, Nov. 1, 1926, pp. 650-653, 6 figs. Operation of mill trains and auxiliaries, elastic drive and reduction gear, cooling beds, etc.

MANIPULATORS. Billet-Piercing Mill Manipulator. *Iron Age*, vol. 118, no. 25, Dec. 16, 1926, pp. 1683-1684, 1 fig. Device carrying two mandrels, one being in action while other is being unloaded.

PROGRESS, 1926. Rolling Mill Practice Advances in 1926. *Iron Trade Rev.*, vol. 80, no. 1, Jan. 6, 1927, pp. 25 and 121. Review of developments in United States.

SAFETY IN DESIGN. Bethlehem Steel Company's New Gautier Mills from a Safety Standpoint. J. Northwood. *Iron & Steel Engr.*, vol. 3, no. 12, Dec. 1926, pp. 495-497, 7 figs. In designing and laying out new mills, question of safety was important consideration and every detail was worked out carefully so that mills could be operated with maximum production and safety.

TECHNICAL CONTROL. The Application of Technical Control to the Metal Rolling Mill. W. B. Price. *Metal Industry*, (N. Y.), vol. 24, nos. 11 and 12, Nov. and Dec. 1926, pp. 445-448 and 497-499, 14 figs. How Scovill Manufacturing Co. uses laboratory to control plant. Dec.: Selection of proper metal for job; how the microscope can be aid in manufacturing department. See also *Metal Industry* (Lond.), vol. 29, no. 25, Dec. 17, 1926, pp. 583-584, 8 figs.

TIME STUDIES. Comparative Time Studies of Rolling Mills with Special Regard to Rod Mills (Vergleichende Zeitstudien an Walzwerken, insbesondere an Drahtstrassen), K. Rummel and P. Berger. *Stahl u. Eisen*, vol. 46, no. 47, Nov. 25, 1926, pp. 1649-1666, 17 figs. Time studies of five different rod mills and results; time indicator; conclusions based on investigation.

SHEET METAL

SHEARING AND BLANKING. Wear Re-

sistance of Cutting Edges of Blanking Dies and Shear Blades, W. J. Merten. *Am. Soc. for Steel Treating—Preprint*, for mtg. Jan. 20-21, 1927, no. 2, 11 pp., 6 figs. Discusses effect of shearing and blanking of sheets and plates upon cutting edge of shear blades and die parts when these sheets and plates are covered with hammer or roll scale, or when intensely hard and abrasive constituent irregularly but profusely scattered or dispersed through it, e. g., iron silicide in silicon sheet; review of various methods employed to hinder fragmentation of hard crystals and imbed them when fractured so as to avoid and neutralize their grinding effect upon cutting edge; utility of uniformly hard die parts for burrless blanking and shear cutting.

STEEL

AUSTENITIC STRUCTURE. The Decomposition of the Austenitic Structure in Steel, R. L. Dowdell and O. E. Harder. *Am. Soc. for Steel Treating*, vol. 11, no. 1, Jan. 1927, pp. 17-41, 1 fig. Summary of work done by previous investigators; effect of quenching on austenitic structure; effect of tempering on decomposition; effect of stress on austenitic decomposition during quenching.

BOILER. Basic Steel. Metallurgist (Supp. to *Engineer*, vol. 142, no. 3703), Dec. 31, 1926, pp. 178-179. Discusses problem of cracking in boiler plates; points out that basic steel has been much more widely used in Germany and America than in England; unsound steel, by whatever process it is produced, is highly undesirable for boiler-plate purposes; while basic steel is more usually produced of "rimming" variety, this can scarcely be inherent defect of basic process, but must be regarded as result of particular type of practice.

BOILER. The Behavior of Boiler Materials in Operation (Das Verhalten der Kesselbaustoffe im Betrieb), Fry. *Kruppsche Monatshefte*, vol. 7, Nov. 1926, pp. 185-196, 31 figs. Requirements of boiler materials and how they are met by present quality of low-carbon steel; causes of poor behavior of steel; effect of aging, and means of reducing damages due to aging; describes new unalloyed low-carbon steel which meets all requirements of good boiler steel, especially with regard to strength and weldability, and which, in addition, does not become brittle even with 10 per cent cold deformation and subsequent annealing; results of tests.

CEMENTATION. Cementation of Metallurgical products and Its Generalization (La cimentation des produits métallurgiques et sa généralisation), I. Guillet. *Annales de l'Association des Ingénieurs sortis des Ecoles Spéciales de Gand*, vol. 16, series 5, 1926, pp. 181-229, 18 figs. Most recent progress in cementation of common and special steels, nitration, metallic cementation, etc.; spheroidization, calorization; cementation applied to copper and its alloys; general theory of cementation.

CONSTITUTION. The Constitution of Steel and Cast Iron, F. T. Sisco. *Am. Soc. for Steel Treating*, vol. 11, no. 1, Jan. 1927, pp. 115-128, 9 figs. Discusses effect of various elements other than carbon added to or present as impurities in normal carbon steels; these elements found in practically

all carbon steels are manganese, silicon, sulphur and phosphorus; in addition most steels contain traces and occasionally appreciable amounts of foreign matter such as slag and other nonmetallic inclusions and gas; effect of common elements and more prominent impurities on structure and physical properties of carbon steels.

CORROSION. The Corrosion of Steel by Lubricating Oils Containing Small Amounts of Moisture and Alkalies, W. Singleton. *Indus. Chemist*, vol. 11, no. 23, Dec. 1926, pp. 540-549, 36 figs. Investigation by author of corrosion produced by high-grade lubricating oils upon steel, particularly in presence of small amounts of alkali salts; such conditions are liable to arise in connection with operation of steam turbines.

DIE. Selection of Die Steel (Einige Richtlinien für die geeignete Auswahl von Gesenkstahl), W. Oertel. *Maschinenbau*, vol. 5, no. 19, Oct. 7, 1926, pp. 878-880, 4 figs. From tests it appears that tungsten steels and high chromium steels offer best combination of properties: 0.6 to 0.7 per cent carbon steel with 0.6 to 8 per cent manganese has been used but meets requirements only for not very severe conditions.

DRILL. United Verde's Drill-Shop Practice, W. P. Goss. *Eng. & Min. Jl.*, vol. 123, no. 1, Jan. 1, 1927, pp. 4-9, 9 figs. Systematic handling, forging and tempering cut mining costs; steel is punched and forged with one heat; use of pyrometers with forging furnace; two thermocouples on tempering machine; carbon content of steel from 0.80 to 0.85 per cent.

GASES IN. The Determination of Gases in Iron and Steel (Die Bestimmung der Gase in Eisen und Stahl), P. Klinger. *Stahl u. Eisen*, vol. 46, nos. 37, 38 and 39, Sept. 18, 23 and Oct. 7, 1926, pp. 1245-1254, 1284-1288 and 1353-1356 and (discussion) 1356-1358, 4 figs. Review of published works on subject; hot extraction in vacuo with and without flux and evaluation of results; cold decomposition in vacuo with iodine, bromine, copper chloride and mercuric chloride; solubility of CO and CO₂ in iron; conclusions. See translated abstract in *Metallurgist* (supp. to *Engineer*, vol. 142, nos. 3698 and 3069, Nov. 26 and Dec. 31, 1926, pp. 166-167 and 179-180).

HARDENED, TESTING. Testing Hardened Steel (Provning av härdat stal), A. Lundgren. *Jernkontorets Annaler*, vol. 811, no. 8, 1926, pp. 325-361, 30 figs. Report of Swedish Testing Station on mechanical properties, microstructure, mechanical tests; effect of annealing and hardening temperatures, etc.

HARDENING. New Process for Superficial Hardening of Steels by Means of Nitration (Nouveau procédé de durcissement superficiel des aciers par nitruration), L. Guillet. *Société des Ingénieurs Civils de France—Mémoires et Compte Rendu*, vol. 79, nos. 7 and 8, July-Aug. 1926, pp. 519-523. New process due to Fry; finished pieces of certain special steels are heated to 500 degrees Cent., in ammonia atmosphere under pressure; scleroscope and ball-hardness figures, etc.

NONMETALLIC INCLUSIONS. Identifying Nonmetallic Inclusions in Iron and Steel, W. Campbell and G. F. Comstock. *Foundry*, vol. 55, no. 1, Jan. 1, 1927, supp.

plate. Foundry data sheet. Determination of inclusions in steel.

NORMAL AND ABNORMAL. Progress in Study of Normal and Abnormal Steel, S. Epstein and H. S. Rawdon. *Am. Soc. for Steel Treating—Preprint*, no. 6, for mtg. Jan. 20-21, 1927, 41 pp., 21 figs. Defines meaning of terms, normal and abnormal steel, and illustrates characteristics of normal and abnormal structure in carburizing steel and tool steel; under certain quenching conditions abnormal steel is more prone to give soft spots than normal steel, but with drastic quenching in brine or in sodium hydroxide solution, it is possible to completely prevent formation of soft spots in both normal and abnormal steel; it is shown that normality and abnormality have their origin in deoxidation procedure of steel making and that in particular additions of aluminum and ferrovanadium in mold produced abnormality.

NORMALITY. Normality of Steel, J. D. Gat. *Am. Soc. for Steel Treating—Preprint*, no. 7, for mtg. Jan. 20-21, 1927, 43 pp., 28 figs. After conducting some experiments to demonstrate behavior of steels having different grain size and amounts of segregated cementite, author dwells on properties of "cementitic lining" present in abnormal steels arriving at conclusion that resistance to uniform hardening is caused by high oxygen content forming eutectoid alloy with constituents of austenite.

OVERSTRAINING BY BENDING. The Overstraining of Steel by Bending, J. Muir and D. Binnie. *Engineering*, vol. 122, no. 3179, Dec. 17, 1926, pp. 743-744, 5 figs. Reference to paper by A. B. W. Kennedy, published in same journal, June 15, 1923, describing experiments showing how calculated maximum stress at yield point observed in bending test depends on shape of cross-section of steel beams used; shows that increase in yield point is merely apparent; some material in outside fibers of bent beam yields when stress, as calculated by elementary theory of bending, reaches yield-point stress as given by simple tensile test, but there is then new distribution of stress which necessitates modification of elementary theory.

PROPERTIES. Effect of Gas on Properties of Steel (Influence des gaz sur les propriétés des aciers), L. Guillet and A. Roux. *Académie des Sciences—Comptes Rendus*, vol. 183, no. 18, Nov. 3, 1926, pp. 717-719. Compares mechanical properties of steels after annealing in air and in vacuum; shows among other things that steel annealed in vacuum has finer crystalline structure than if annealed in air.

TESTING. Some Limitations of Steel Testing and Inspection. *Mech. World*, vol. 80, nos. 2084 and 2085, Dec. 16 and 17, 1926, pp. 465-466 and 482-483. Comments concerning actual figures obtained from pulling of tensile test piece; inspection of forgings.

STEEL CASTINGS

CAPACITY AND PRODUCTION. High Capacity in Steel Castings. *Iron Age*, vol. 119, no. 1, Jan. 6, 1927, pp. 72-73, 6 figs. Presents tables showing capacity, 1925 production and percentage of capacity represented by production for five leading types of casting plants: acid, open-hearth, basic open-hearth, electric, converter and crucible;

six diagrams showing steel castings over specific classes of castings.

INGOT DEFECTS. Ingot Defects. *H. G. Monypenny*, vol. 29, no. 24, 1926. Deals with blowholes, effervescent steel, discussion before

STEEL, HEAT-TREATED. GEAR-TEETH. Hardened Gear, *Engineering*, no. 3701, Dec. 1926. Describes new process as Shorter process. Hardening Co.; heating each tooth in blowpipe and in furnace with copious steam; of hardened steel while interior condition. *Engineering World*, vol. 80, no. 1, 1927, p. 488, 1 fig.

METALLOGRAPHY. Metal and Metallography Course in the Metallurgy, H. C. King. *Iron Age*, vol. 119, nos. 10, 11 and 12, 1926, pp. 914, 925-926, 927 and 283; and 451-455, 730. Case-hardening elements. Martensite elements. Juniper nickel-chromium steel. Sept.: Silicon and tungsten speed steel, cooling theory of hardening. Equipment used. Furnaces for hardening.

OIL-HARDENING. Heat Treatment of Oil-Heated Forging-Stamping Dies. *Engineering*, vol. 121, no. 1, Jan. 1927, pp. 120-121. Heat treatment for blanking and drawing dies.

PROGRESS, 1926. Heat Treating, Rev., vol. 80, no. 1, Jan. 1, 1927, pp. 119-120, 121-122. Electrical heating of furnaces has been developed; featuring this type are semi-automatic temperature control baths for annealing developed for flat plates; review of processes.

STANDARD HEAT TREATMENT. New Heat Treatment, Engrs.—Jl., vol. 556. Subdivisions recommended for Steel 4615, 4616, hardening.

TEMPERING. Tool Steels, Vanadium-Heat Treatment. *Engineering*, vol. 121, no. 1, Jan. 1, 1927, pp. 444-445. of investigating heating in temperature drawing medium.

six diagrams show history of production of steel castings over past quarter century; specific classes of castings.

INGOT DEFECTS. The Influence of Steel Ingot Defects in Subsequent Manufacture, H. G. Monypenny. *Metal Industry (Lond.)*, vol. 29, no. 24, Dec. 10, 1926, pp. 565-566. Deals with blowholes, pipe and segregation, effervescing steel. Abstract of paper and discussion before Manchester Met. Soc.

STEEL, HEAT TREATMENT OF

GEAR-TEETH HARDENING. Surface-Hardened Gear Teeth. *Engineer*, vol. 142, no. 3701, Dec. 17, 1926, pp. 661-662, 4 figs. Describes new system of hardening known as Shorter process, developed by Patent Gear Hardening Co.; process consists of intensely heating each tooth locally with acetylene blowpipe and immediately cooling it again with copious supply of water; result is layer of hardened steel on wearing part of tooth, while interior is left in its tough normal condition. See also description in *Mech. World*, vol. 80, no. 2085, Dec. 17, 1926, p. 488, 1 fig.

METALLOGRAPHY AND. Heat Treatment and Metallography of Steel—A Practical Course in the Elements of Physical Metallurgy, H. C. Knerr. *Forging-Stamping-Heat Treating*, vol. 12, nos. 1, 2, 3, 4, 6, 8, 9, 10, 11 and 12, Jan., Feb., Mar., Apr., June, Aug., Sept., Oct., Nov. and Dec. 1926, pp. 9-14, 52-56, 99-104, 127-131, 212-219, 275-279 and 283; 339-343, 392-397, 428-432 and 451-455, 74 figs. Jan.: Carburizing and case-hardening. Feb.: Effects of alloying elements. Mar. and Apr.: Special alloying elements. June: Chromium-vanadium and nickel-chromium steels. Aug.: Manganese. Sept.: Silicon and molybdenum. Oct.: High-speed steel, composition, metallography and theory of hardening; heat treatment. Nov.: Equipment used in heat treatment. Dec.: Furnaces for heat treatment.

OIL-HARDENING STEEL. Heat Treatment of Oil-Hardening Steel, A. Mumper. *Forging-Stamping-Heat Treating*, vol. 13, no. 1, Jan. 1927, pp. 9-11, 5 figs. Deals with heat treatment of oil-hardening tool steel for blanking and stamping dies.

PROGRESS, 1926. Automaticity Gains in Heat Treating, H. M. Boylston. *Iron Trade Rev.*, vol. 80, no. 1, Jan. 6, 1927, pp. 28-29, and 119-120, 2 figs. Development of electrical heating to all kinds of heat treatment furnaces has been most marked during past year; featuring recent furnace installations of this type are devices for automatic and semi-automatic charging, unloading and temperature controlling; installation of salt baths for annealing coiled wire; new steel developed for forging and case-hardening purposes; review of research and tests.

STANDARD SPECIFICATIONS. Proposed New Heat Treatments. Soc. Automotive Engrs.—Jl., vol. 19, no. 6, Dec. 1926, p. 556. Subdivision on Physical-Property Charts recommended heat treatments for S. A. E. Steel 4615, intended primarily for case-hardening.

TEMPERING. Tempering Plain Carbon Tool Steels, V. E. Hillman. *Forging-Stamping-Heat Treating*, vol. 12, no. 12, Dec. 1926, pp. 444-446 and 450, 3 figs. Results of investigation into effect of prolonged heating in tempering plain carbon tool steels; drawing mediums and furnace tempering.

STEEL MANUFACTURE

RESEARCH. Fundamental Research in Steel Manufacture, C. H. Herty, Jr. *Am. Soc. for Steel Treating—Preprint*, no. 5, for mtg. Jan. 20-21, 1927, 14 pp., 5 figs. Classifies problems encountered in making of steel and points out that field for fundamental research in its manufacture is astounding in its magnitude and intricacies; consideration of fundamental research which deals primarily with slag-metal reactions giving particular attention to formation and elimination of nonmetallic inclusions formed from manganese, silicon and aluminum.

STEEL, HIGH-SPEED

COBALT STEEL. Properties of High-Speed Cobalt Steel (Eigenschaften cobalt-legierter Schnellarbeitsstähle), W. Oertel. *Motorwagen*, vol. 29, no. 30, Oct. 31, 1926, pp. 742-746, 7 figs. Experiment with two cobalt steels in shop with 10 lathes showed that 5 per cent cobalt steel made possible saving of \$1500 per year, while one containing 8 per cent made possible saving of over \$3000; metallography of these steels.

STEEL INDUSTRY

PRODUCTION, 1926. What Steel Was Made and Where it Went in 1926. *Iron Age*, vol. 119, no. 1, Jan. 6, 1927, pp. 6-9, 4 figs. Record production in rolled steel; chief increases in steel rails and pipe; 3% of steel is absorbed by railroads, construction work, automobiles, and oil and mining developments.

STEEL MANUFACTURE

ARMOUR PLATE. Armour Plate and Steel Manufacture, L. Bacle. *Engineering*, vol. 122, no. 2178, Dec. 10, 1926, pp. 728-729. History of naval armour at early date and review of progress with special reference to work of French metallurgists. Paper read before Brit. Section of Société des Ingénieurs Civils de France.

ROLLER BEARINGS, FOR. Bearings Require Clean Steel, J. D. Knox. *Iron Trade Rev.*, vol. 79, nos. 26 and 27, Dec. 23 and 30, 1926, pp. 1622-1624 and 1628 and 1675-1679, 17 figs. In plant of Timken Roller Bearing Co., Canton, O., all raw materials charged into electric furnaces are of selected grades; chips and turnings are pressed into briquettes; care is exercised in preparing ingot molds and in pouring metal; ingots converted into blooms by 3-high mill in control of one operator; seamless mill produces stock for cones and cups.

STEEL WORKS

GAS MEASUREMENT IN. Gas Volume Measurement and Its Application in Steel Works (Die Gasmengenmessung und ihre wärmestatische Anwendung im Stahlwerk), C. Kisker. *Kruppsche Monatshefte*, vol. 7, Nov. 1926, pp. 204-211, 6 figs. Measuring methods and evaluation of diagrams; errors of approximate method; regulations for maintenance of volume indicator; monthly record of an open-hearth furnace; value of gas measurement in steel works.

STRUCTURAL STEEL

CORROSION. Corrosion of Structural Steel, F. N. Speller. *Can. Machy.*, vol. 36, no. 23, Dec. 2, 1926, pp. 25-30 and 44-48, 4 figs. Established facts regarding corrosion

in general; in corrosion of structural steel atmospheric corrosion plays most important part; effect of copper; preventive measures employed to combat corrosion of steel framework of buildings, bridges and similar structures.

TESTS AND TESTING

MATERIALS. Selecting Material for Service, F. E. Schmitt. Am. Soc. for Steel Treating, vol. 11, no. 1, Jan. 1927, pp. 42-53. Primary trouble is that testing engineer usually measures conventionalized properties, whose correlation with daily service demands is largely unknown; therefore, tests of suitability for desired service should be developed in place of or to supplement present conventionalized tests; in such development of suitability tests, users of materials have excellent opportunity to assist.

TOOL STEEL

FAILURES. Tool Steel Failures—Their Causes and Cures, F. B. Lounsherry. Am. Soc. for Steel Treating, vol. 11, no. 1, Jan. 1927, pp. 101-114, 31 figs. Sets forth various factors which assist toolmaker in selection of steels and in attainment of greatest possible service from manufactured tools; statements are based on data obtained in investigation of from 400 to 500 complaints per year, extending over period of years; investigations show 55 per cent of complaints are due to faults at mill and of these about one-half are due to faulty inspection; author believes that closer control, in melting operations will eliminate much of trouble; electric furnace is valuable aid in this respect; accurate temperature control is imperative.

TUNGSTEN

THORIA, EFFECT OF. Tungsten and Thoria, Z. Jeffries and P. Tarsov. Am. Inst. Min. & Met. Engrs.—Trans., no. 1614-E, Jan. 1927, 17 pp., 15 figs. Presence of metallic thorium in thoriated tungsten; size and dispersion of thoria particles; effect of work and heat on tungsten and thoria; special distribution of thoria in drawn wire; particle growth of thoria and grain growth of tungsten; solubility of thoria in liquid tungsten.

WELDING

GASEOUS ATMOSPHERE. Welding in a Gaseous Atmosphere. Am. Welding Soc.—Jl., vol. 5, no. 12, Dec. 1926, pp. 43-49. Discussion at meeting of Society in Buffalo.

MACHINERY BASES. Designing a Welded Steel Machinery Base, R. E. Kinkead. Machy. (N. Y.), vol. 33, no. 5, Jan. 1927, pp. 377-379, 4 figs. Redesigning of cast iron machinery bases in order to substitute welded steel.

RAILWAY APPLICATIONS. Applications of Welding on Railroads. Am. Welding Soc.—Jl., vol. 5, no. 12, Dec. 1926, pp. 16-24. Discussion of meeting of society in Buffalo.

STEEL FOUNDRY. The Selection of a Welding Process, L. E. Everett. Acetylene Welding & Cutting Jl., vol. 28, no. 6, Dec. 1926, pp. 277-279. Describes conditions leading to selection of welding process in steel foundry, whose production is confined largely to straight carbon steel castings.

STRUCTURAL STEEL. Experience in Welding Structural Steel and Some Conclusions, R. E. Kinkead. Eng. News-Rec., vol. 97, no. 26, Dec. 23, 1926, pp. 1033-1034, 3 figs. Welding applied to steel parts unite up to replace gray iron castings for machine bases and frames; results highly satisfactory.

STRUCTURAL STEEL. Is Structural Welding Dependable. Contract Rec., vol. 40, no. 49, Dec. 8, 1926, pp. 1163-1166. Hardly enough data, according to author, to substantiate claim that it will supplant riveting, may be field for process in time.

UNIVERSITY CURRICULUM. Welding Science in the Engineering Curriculum of Universities. Am. Welding Soc.—Jl., vol. 5, no. 12, Dec. 1926, pp. 32-43. Discussion at meeting of Society in Buffalo.

WATER MAINS. Field Welding Experience on 65-inch Mokelumne Pipe, A. P. Davis. Eng. News-Rec., vol. 97, no. 23, Dec. 2, 1926, pp. 912-914, 4 figs. Both gas and electric methods used in joining pipe for new east bay water supply in California; internal stresses in metal led to change to riveted field joints.

WIRE

COLD WORKING. The Influence of Cold Working on the Physical Properties of Wire, A. J. Michel. Wire, vol. 2, no. 1, Jan. 1927, pp. 10-13 and 28, 4 figs. Shows that aging has same influence upon physical properties after cold working has been completed, as cold working of wire will normally have by itself.

COPPER, ANNEALING TEMPERATURE. Note on the Distribution of Energy in Worked Metals and the Effect of Process Annealing Temperature on the Final Annealing Temperature of Fine Copper Wire, L. Zuckrnick and R. S. Dean. Am. Inst. Min. & Met. Engrs.—Advance Paper, no. 1613-E, Jan. 1927, 3 pp., 2 figs. Results of experiments made on copper wire annealed at 400 and 220 degrees Cent., respectively; shows that annealing temperature of hard-drawn copper wire depends to marked degree on previous treatment as regards cold working and annealing.

IRON, HARDENING. Hardening of Iron Wire, H. Altpeter. Wire, vol. 2, no. 1, Jan. 1927, pp. 7-8, 2 figs. Discussion of German practice in heating, quenching and tempering of wire. Translated from Stahl u. Eisen.

X-RAYS

APPLICATION TO METALS. Radiography, J. T. Norton. Tech. Eng. News, vol. 7, no. 6, Dec. 1926, pp. 263-265 and 298, 6 figs. Uses of X-rays for examination of interior of opaque objects; materials to which high-voltage radiography is most commonly applied are castings and forgings; classes of defects in castings; examples of application of radiography.

ZINC

PLASTIC DEFORMATION. Plastic Deformation of Coarse-Grained Zinc, C. H. Mathewson and A. J. Phillips. Am. Inst. Min. & Met. Engrs.—Trans., no. 1623-E, Jan. 1927, 45 pp., 52 figs. Describes number of observations of crystallographic behavior under stress of single crystals grown by special annealing in strip zinc.

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STANDING OF THE CHAPTERS

IN the following tabulation there appears the relative membership standing of the 29 chapters and 2 groups of the Society as of February 1, 1927:

	GROUP I	GROUP II	GROUP III	
1. Detroit	408	1. Hartford	141	1. Montreal
2. Cleveland	402	2. Lehigh Valley	133	2. Los Angeles
3. Chicago	388	3. Milwaukee	129	2. New Haven
4. Philadelphia	351	4. Golden Gate	117	4. Washington
5. Pittsburgh	324	5. Indianapolis	95	5. Tri-City
6. New York	269	5. Syracuse	95	6. Rockford
7. Boston	245	5. Cincinnati	95	7. Rochester
		8. St. Louis	84	8. Toronto
		9. Buffalo	58	9. Worcester
		10. North-West	57	10. Providence
				11. Schenectady
				12. Southern Tier
				13. Fort Wayne
				14. Springfield

THERE were 128 new members elected to membership in the Society. The net gain for the month, however, was only 41, due to 65 being dropped for non-payment of dues and 22 resignations and deaths. The net gain of 41 members for January, however, is practically five times that of January, 1926, when the net gain was only 8 members.

GROUP NO. I—Congratulations to Detroit. You had a splendid record last month with 29 applications, which indicated that chairman Bob Atkinson and the other members of his executive and membership committees have been on the job. With a net gain of 21 new members you passed both Chicago and Cleveland. The other members of Group I had slight gains, but insufficient to change the relative positions as published in December TRANSACTIONS.

GROUP NO. II—Hartford is to be congratulated on gaining and keeping position No. 1. You had a net gain last month of 3 members, while your nearest competitor, Lehigh Valley, suffered a loss. We have in Group No. II something we have never had before, a "triple tie", with Indianapolis, Syracuse and Cincinnati with 95 members each, all endeavoring to occupy lower berth No. 5. St. Louis had a gain of 5 members last month.

GROUP NO. III—Montreal still heads the group with Los Angeles and New Haven tied for second place. Several changes have taken place in the arrangement of Group III. Toronto and Worcester have exchanged places, as have also Providence and Schenectady. Southern Tier has moved up from position 14 to position 12. Fort Wayne and Springfield have dropped back one place as a result of the Southern Tier advance.

BOSTON CHAPTER

One of the most interesting talks ever presented before the Boston Chapter was given by J. P. Gill, metallurgist for the Vanadium Alloy Steel Company, at the January meeting held at the Massachusetts Institute of Technology on Friday, January 7, 1927.

Mr. Gill selected as his subject, "High Speed Steel,—Its Composition, Structure and Treatments", and divided his talk into five parts. The first part consisted of an elaborate display of a large number of Photomicrographs and fractured specimens to show the effect of time and temperature of heat treatment on the fracture, structure and etching time of drawn and undrawn specimens and tools. The second section consisted of two reels of movies taken at the plant of the Vanadium Alloy Steel Company at Latrobe, Pennsylvania. Both the exhibit and the pictures brought out much favorable comment.

With the aid of charts, he then showed the analysis of the several types of high speed steel being manufactured at the present time and after discussing the effect of each element, he gave the advantages and disadvantages, if any, of each type. After some discussion by those present, he proceeded to show the good and bad effects of manufacturing methods on the quality of the high speed steel bars and emphasized particularly that presses, light hammers, as well as rolls, were not satisfactory for breaking down the ingots, as a heavy steam hammer blow was necessary to break up the lines of tungsten segregate.

The fifth and last section of the paper was devoted to the effect of different heat treatments. Methods of preheating; time and temperature of the high heat; quenching mediums and drawing temperatures were fully discussed.

In answer to questions, Mr. Gill stated that he felt that a one hour draw at 1050-1100 Fahr. was correct and that no advantages were gained by a longer draw. He also felt that a single draw was sufficient. He preferred wet grinding to dry on production work, provided the proper wheel and sufficient water were used. He admitted that quenching in a salt bath at 1200 Fahr. gave a tougher tool and one that was satisfactory under ordinary conditions, if it had been heated to the correct high temperature and properly drawn. He stated, however, that the maximum efficiency of the tool could never be obtained by this treatment and that an oil quench was necessary to break up any tungsten segregate.

Speaking of secondary hardness, he said that a correctly hardened tool would show a higher Brinell figure after it had been drawn, but that it was difficult to notice any increase in Rockwell hardness. He referred the question to S. P. Rockwell, who was present, and it is expected that something will be heard from the latter at a later date. Considerably more discussion followed and it was not until 10:30 that the vice-chairman could get the floor to ask that a rising vote of thanks be given the speaker by the more than 125 members and guests.

At 6:30 p. m. dinner was served in the Walker Memorial to ninety members of the chapter. At the conclusion of the dinner, two abstracts from

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the world's latest metallurgical literature were given by Dr. G. B. Waterhouse, professor of metallurgy at Massachusetts Institute of Technology. The first was entitled "Heat Treatment of Steel Rails", being an account of the work carried on by Messrs. Thiabaudier and Viteaux, at the plant of Neuves Maisons in France. Several thousand tons of rails have been treated by the process and the service tests have so far proven satisfactory. Methods of treatment and Brinell hardness figures were given and may be obtained from Dr. Waterhouse by anyone interested. The second abstract was "Testing the Cutting Efficiency of High Speed Tool Steel", by Dr. F. Rapatz, Duesseldorf, Germany. The importance of time and temperature of the high heat and its relation to the cutting efficiency was fully discussed. The methods of pyrometric control of the furnaces were very interesting and the paper was illustrated with many fine micrographs. The original paper appeared in a recent issue of *Stahl und Eisen*. *H. E. Handy.*

CHICAGO CHAPTER

The regular monthly meeting of the Chicago Chapter was held January 13 at the City Club. We were fortunate to obtain Joseph A. Reinhardt, assistant chief engineer of the Western Clock Company, La Salle, Illinois, as the speaker of the evening. His subject was "Metallurgy in the Clock Industry." He brought out in detail the thoroughness used in the control of raw materials, ferrous and nonferrous, in the manufacture of clocks. From the talk of Mr. Reinhardt, it is evident that the metallurgist is coming into "his own," in the manufacture of clocks. To illustrate in a practical manner, the speaker brought numerous samples of clock parts to demonstrate the points he brought out.

CINCINNATI CHAPTER

Dr. R. J. Anderson, president of Robert J. Anderson, Inc., Cincinnati, addressed the Cincinnati Chapter of American Society for Steel Treating on January 6, 1927. The subject was, "Aluminum Castings and Their Heat Treatment."

Dr. Anderson pointed out that the aluminum industry has shown continuous and phenomenal growth, the output increasing at the rate of 100 per cent every five years.

The cause of some of the early difficulties in the casting of aluminum was discussed and the relative fields of usefulness of sand, permanent mold and die cast aluminum alloys were pointed out. The sand mold is useful for large castings in any quantity and small castings which will be made in only small quantities. The sand castings are prone to unsoundness, but are useful for such parts as crank-cases, gear-housings and the like.

The permanent mold casting has a wide field of usefulness for parts that are to be produced in quantity and which must possess high mechanical strength and freedom from porosity. Each permanent mold job requires careful study to insure proper feeding during solidification so that consistently reliable castings will be produced.

The die casting is useful where very large quantities of castings will

be used and where the presence of slight internal shrinkage will not be objectionable.

Numerous aluminum alloys have been proposed and used for the production of castings. The principal alloy in use today is the modified No. 12 alloy containing about 7.5 per cent copper, 1.5 per cent zinc and small amounts of iron and silicon with the balance aluminum.

The No. 12 alloy is used for about 50 per cent of the total production of aluminum alloy castings today.

The eutectic aluminum-silicon alloy, Alpax, modified by the introduction of a trace of sodium, either directly or through a fluoride flux, is a very valuable casting alloy and is rapidly coming into wide use. Its freedom from cracking and low shrinkage are of great value for the production of intricate castings.

Dr. Anderson then explained the method of heat treating aluminum alloys, both cast and forged and pointed out that the hardening was the result of precipitation of a compound such as $Mg_2 Si$ or $Cu Al_2$, which has a lesser solubility at low temperatures than at high temperatures.

The various grades of aluminum and aluminum hardeners were then described and the subject of secondary metal was briefly discussed. Secondary metal when produced under the proper control and with carefully selected scrap will produce castings which are equal to or superior to those produced from virgin metal.

The meeting closed with a long discussion of the merits and demerits of zinc content alloys. One could not help feeling that the application of high strength aluminum castings will rapidly grow and displace far heavier ferrous castings where weight and appearance are factors to be considered.

The night course in metallurgy given at the University and sponsored by the American Society for Steel Treating has exceeded the most optimistic predictions with an enrollment of about 90. Both Professor Enos, who is giving the course, and Dr. Hartzell and his committee deserve great credit for putting this educational campaign across so effectively. An advanced course has been arranged for the second semester. This will cover heat treating and various metallurgical problems of a practical nature.

At the next meeting of the American Society for Steel Treating on February 3, T. H. Nelson, chief metallurgist of the Ludlum Steel Corporation, will deliver a talk. The subject will be the new surface hardening steel, Nitr alloy. Mr. Nelson has just returned from Europe and will have a wealth of new information on this interesting subject. *E. M. Wise.*

The second semester in metallurgy and heat treating at the University of Cincinnati offers advanced work for those who have completed last semester's course and is also open to men whose educational training is sufficient and those whose practical experience is adequate. These courses are offered in cooperation with the American Society for Steel Treating and have proven of great value to those who have pursued them.

In the second semester's course much attention will be given to laboratory work and demonstrations of a practical nature.

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CLEVELAND CHAPTER

On Friday evening, January 21, 1927, the Cleveland Chapter of the American Society for Steel Treating had an attractive subject at their meeting.

Dr. Albert Sauveur, Gordon McKay Professor of metallurgy and metallography, Harvard University, was introduced to the chapter by Prof. H. M. Boylston, professor of metallurgy and metallography at Case School of Applied Science. Prof. Boylston was a pupil of Dr. Sauveur at one time.

Dr. Albert Sauveur's subject was "Distinguished Metallographists, Past and Present." This made a very attractive and historical talk on metallurgy.

Each man was linked with some definite phase of metallurgy which had won him recognition and thereby made the address very interesting. The talk was accompanied by slides showing pictures of metallurgists.

About 125 members and guests were present, 30 being present at dinner.

A. E. Buelow.

HARTFORD CHAPTER

On December 7, the Hartford Chapter held its regular monthly meeting in the Auditorium of the Hartford Electric Light Company. The speaker of the evening was Radcliff Furness, superintendent of steel melting and forging, Midvale Steel Company, Nicetown, Pa. Mr. Furness gave a very interesting talk on the different melting processes used in the making of steel, dwelling principally on the open hearth and electric furnace methods.

The Bessemer process was not taken up as Mr. Furness had little experience with this type of melting units. The crucible process he summed up in the following words: "You get out of the pot what you put in it."

The acid open hearth and the basic open hearth processes were next compared. Mr. Furness stated that it was more difficult to produce a high grade basic open hearth product than the acid open hearth, as it required more skill, the chances of success not so great and the chemical reactions not so definite.

The merits of the crucible and electric furnace steels were compared and the speaker was of the opinion that any steel that can be produced in the crucible can be produced in the electric furnace equally well. Cutting tests on high speed steels conducted at the Midvale plant from both the crucible and electric furnace, indicated that the electric product was superior to the crucible.

The making of large forgings was next taken up. One of the largest made by the Midvale Company required a 400,000 pound ingot, the forging being 45 feet long with an inside diameter of 72 inches and a wall thickness of 5 inches and closed at one end. Mr. Furness believes this is the largest forging ever made.

After the paper the discussion lasted for over an hour and a half. Mr. Furness answered all questions to everyone's satisfaction and cleared up a good many points concerning the manufacturing of steel which were not very well understood by the consumer. Talks of this nature are very profitable to the average steel treater because of the information obtained that can be applied to the purchasing and using of steel. *H. J. Fischbeck.*

HARTFORD CHAPTER

The regular meeting of the Hartford Chapter was held in the Auditorium of the Hartford Electric Light Company on the evening of January 11.

The paper presented by A. C. Lusher of the Scovil Manufacturing Company, covered the field of wrought brasses. It did not include the cast alloys, such as bearing bronzes. In order to maintain uniformity of product, all raw materials are bought under rigid specifications. Incoming shipments are checked up in the laboratory. Electric furnaces are used exclusively for melting. The speaker indicated that the pouring temperatures are carefully checked with pyrometers.

All virgin metal cannot be used; a percentage of selected scrap must be employed in order to make good brass.

In addition to chemical composition the metal must be free of flaws, gas holes, occlusions, etc., and have the proper thermal treatment before it goes to the trade. The former condition is checked by the microscope.

The speaker touched on the extrusion process. This method of manufacture is used on round and many irregular cross-sections. Ordinarily bars are cold drawn afterwards, though not always, in order to take care of size variations.

A brass suitable for extrusion must not contain over 64 per cent copper. Otherwise the metal will manifest hot shortness. A special high speed is used for the extrusion dies, running about 12 per cent tungsten. The dies are heat treated before machining.

A very lively discussion followed the presentation of the paper. This was the first paper on non-ferrous alloys, and from the interest shown, it would seem very desirable that at least one paper on these metals should be included on the yearly program.

H. J. Fischbeck.

INDIANAPOLIS CHAPTER

On Monday evening, December 13, more than 75 members and guests attended the regular monthly meeting of the local chapter of the Society and all pronounced it to be one of the finest meetings ever staged in this city. The extreme enthusiasm was due to the fact that it was an open discussion meeting and the atmosphere was such that many of our members realized the great value of putting questions pertaining to their troubles before the men present and learning some of the "shop kinks" from fellow members. This was our second consecutive "Open Discussion" meeting and the officers were well pleased with the outcome as many of our learned members who had remained silent in all previous meetings finally were fighting for an opportunity to talk.

That our open meetings are a marked success is indicated by the fact that 10 new members were added to our list that night. Our January meeting which will be held in the Auditorium of the Y. M. C. A. on Monday, January 17, will also be an open discussion meeting and we will be pleased to have with us that evening F. J. Oaks, general superintendent of the Link Belt Company, Dodge plant, who will lead the discussion on "Quenching". Mr. Oaks is better known to the local members as president of The National Quenching Association, and promises to give the mem-

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On Monday chapter, about pated in the Y. M. C. A. tendent of the 1915, who pro "Quenching" tically all pre is and how i beneficial res many of tho resultant sava quality.

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bers and guests some interesting information regarding quenching.

C. H. Beach.

On Monday evening, January 17, the members and guests of the local chapter, about one hundred in number, enjoyed a fine dinner and participated in the general discussion which was held at the Auditorium of the Y. M. C. A. We were deeply indebted to Frank Oaks, general superintendent of the Dodge plant of The Link Belt Company, this city, since 1915, who presented a most interesting and educational practical talk on "Quenching" and who led the general discussion. Needless to say, practically all present left the meeting with a broader idea of what quenching is and how it should be conducted, together with the knowledge of the beneficial results to be obtained from proper quenching. Undoubtedly, many of those present will be able to follow his suggestions with the resultant saving of time and money to say nothing about the better quality.

Since the inauguration of the open discussion meeting, we have been able to develop a very intimate and friendly atmosphere in which every one seems to be very eager to find the "WHY" of their troubles, and no one now hesitates to ask his colleague. The manifestation is evident from the increase in our membership.

Our usual orchestra was on hand to furnish plenty of music and David Killion of The Link Belt impersonating a "wise man" predicted what the new year had in store for us and promised every member Great Success provided they would spend a little time in attending the meetings and digest, at least partially, the wonderful store of knowledge appearing in the monthly TRANSACTIONS. Success and advancement is already with us.

C. H. Beach.

MONTREAL GROUP

In that it dealt, for the most part, with work that has been carried on in Montreal, the address given by Charles McKnight of the development and research department of the International Nickel Company, New York, in Montreal on January 10, was one of the most interesting ever heard by the Montreal group of the American Society for Steel Treating.

Mr. McKnight devoted the first part of his talk to a description of the developments that have been made in the application of nickel steel to locomotive boilers. He stated that the work that had been carried on by the Canadian Pacific Railway in this regard was not only many years in advance of its time, but it was also technically and industrially sound. He continued that this work done by the Canadian railway was one of the greatest steps in locomotive engineering that has been made in this century.

Illustrative of the widespread attention that this development has created is the fact that at the present time there are about 120 locomotives in the process of manufacture in the United States along similar lines.

The use of 3 per cent nickel steel boilers was decided upon by the engineers of the Canadian Pacific Railway when they were confronted with the conflicting demands for more power with no increase in weight. Their locomotives were already up to the limit of weight and size, and so it was

necessary to design one that could be constructed without increasing the size, and using plates of the same thickness. The use of nickel steel boilers has enabled them to increase the boiler pressure from 200-250 pounds to the square inch.

In his talk Mr. McKnight went on to show other advantages that the use of nickel steel offered in boilers, and showed how it was being used for many other purposes such as boiler tubes, locomotive side frames, pistons, submarine cables, etc.

Robert Job was chairman of the meeting.

D. G. MacInnes.

NEW HAVEN CHAPTER

The regular monthly meeting of the New Haven Chapter was held on Thursday, January 13.

The meeting was preceded by a dinner at the Hotel Bishop and the amount of enthusiasm shown at the dinner in reference to the subject of hardness gave promise of a lively discussion.

At eight o'clock we gathered at the Hammond Laboratory of Yale University, and after a short business session, the Chairman, C. J. Sauer, introduced the speaker of the evening, T. Y. Olsen, vice-president of the Tinius Olsen Testing Machine Company, Philadelphia, Pa. The speaker chose as his subject "Recent Development in Steel Testing Apparatus," which was well covered by his talk and illustrated with slides. About a quarter-past nine, the chairman threw the meeting open for discussion and from then until a quarter to ten, the questions flew thick and fast. It was impossible to carry on the questions any later as the speaker had to catch a train for Montreal. From the smile on his face as he left the room, it would appear that he anticipated a very pleasant trip to Canada. Well, I cannot censure him for that, but we were all sorry that the evening meeting adjourned so early because many questions remained unanswered.

After the speaker left, the business session was again resumed, and the first matter taken up was the attendance prize donated by W. H. Duley of the Colonial Steel Company. It is usually customary with us to have the speaker of the evening draw out the winner, but as this was impossible, it fell to the lot of "your humble servant" to do the honors. Well, as we are always doing something different in New Haven, the name which was drawn out of the hat was that of the speaker of the evening. Of course as he had left, the prize had to be mailed and we trust each time he uses it he will remember the New Haven Chapter.

The membership campaign, which closed on January 1, was the next matter of business, but the announcement of winners was carried over one month.

We were indeed glad to see several of our new members present, and also one of the old guard, Major Bellis, out after being absent from several meetings.

Our meetings this year cover a wide field and everyone is well worth attending. Our attendance is good, but we want more out, so avail yourself of the excellent program arranged by the committee. *W. G. Aurand.*

NORTHWEST CHAPTER

On Monday evening, January 10, members and guests of Northwest Chapter enjoyed a most entertaining and educational talk on tool steel, by F. R. Palmer, metallurgist of the Carpenter Steel Company of Reading, Pa.

Although not all of those present were directly interested in tool steel, they obtained much information which can be used very profitably in all branches of steel manufacture.

The lecture dealt mainly with the causes of failure of tool steel, and was illustrated very appropriately with photographic slides. The causes of failure, as pointed out by Mr. Palmer, may be briefly outlined as follows:

1. Inferior steels.

A. The steel must be sound, pure and uniform

2. Improper selection of steel for the work it is supposed to do.

3. Poor mechanical design of tools.

A. Sharp corners and unbalanced sections should be avoided whenever possible.

4. Careless machine work will, many times, cause a tool to fail due to internal strains set up.

5. Faulty heat treating.

A. Reliable equipment, plenty of time, technical knowledge, and common sense are necessary for first class heat treatment.

6. Improper grinding of tools will often result in cracks and checks.

7. Perfectly good tools are often spoiled by careless and improper use.

Mr. Palmer's lecture was delivered most convincingly and in such a manner as to be easily assimilated even by those not making study of the metallurgy of steel.

For the remainder of the evening, Prof. G. C. Priester of the University of Minnesota showed an interesting motion picture of the manufacture and uses of Portland cement.

A. G. Zima.

PHILADELPHIA CHAPTER

The following is the Philadelphia Chapter's notice of the meeting held on January 7, 1927:

"The postponed December meeting of the Philadelphia Chapter was held at the Engineers' Club, 1317 Spruce Street, on Friday evening January 7. The dinner which preceded the meeting was attended by twenty-one members and guests.

The business portion of the program, a feature which is religiously upheld in the chapter, developed the plans of the membership committee under the joint direction of the committee's divisional chairmen, R. C. Gebert, N. C. Einwechter, and R. D. Thomas, for the increasing of the membership of the chapter. This was given a pleasing reception by all present, since drives are sometimes not popular this reaction is noteworthy, and brought out the challenge from T. Wiedemann, that he would obtain one sustaining member for every ten names added to the roll. The only reason for placing this before the readers of the Transactions is to give them warning, especially Joe Emmons of the Cleveland Chapter, that the Philadelphia Chapter is again on the warpath.

The speaker of the evening was C. E. MacQuigg of the research staff, Union Carbide and Carbon Company, New York City. His topic was "Some Present Trends in Engineering Steels." He proceeded to briefly and concisely tell about the role played by some of the alloying elements commonly used with iron and steel, such as silicon, manganese, chromium and vanadium. The illustrations for his paper consisted of most interesting charts, which clearly demonstrated the points discussed and also some splendid photomicrographs.

The discussion which followed the paper brought out confirmation from the speaker that he had practically established the eutectic point for iron-chromium materials in the neighborhood of 2.30 per cent carbon and 27.00 per cent chromium.

Another feature of the evening was a practical appeal for help from one of the chapter's members who is engaged in the production of pens for writing. He complained that in a certain type produced great losses were being encountered due to a peculiar type of cracking or fracture, which only occurred at one point. It was especially interesting to see the various members of the chapter get busy with that problem, since plenty of samples were available. Hand lenses appeared from many pockets, as if by magic, and many squints were made. However, the conservative element of the chapter decided to hold the matter over for further study and thought until the next meeting.

It is believed that this gesture for help will open up a new field in the chapter's many activities since it again strikes at the root of the founding of the Society, namely helpful education for practical men.

Arthur W. F. Green.

PITTSBURGH CHAPTER

The January meeting of the Pittsburgh Chapter was held on the evening of the 6th at the U. S. Bureau of Mines Building.

At 5:45 p. m., there was an executive committee meeting at which data for the new membership list was read and approved.

Following this meeting dinner was served in the Bureau of Mines Restaurant at 6:45 p. m., which was attended by a goodly number of members.

The meeting was called to order in the auditorium at 8 o'clock by Vice-Chairman J. L. Uhler who presided in the absence of Chairman W. H. Phillips.

After a short business session, the chairman introduced the speaker of the evening, T. Holland Nelson, metallurgist of the Ludlum Steel Co., Watervliet, N. Y., whose subject was, "The Krupp Nitrifying Process".

In reviewing the usual casehardening process of today such undesirable features as the following were pointed out:

(1) The coarse crystalline structure often created by the high carburizing temperature necessary which, though capable of refinement, requires heat treatment to accomplish this result.

(2) Such heat treatment results in serious losses due to expansion, deformation or actual breakage in the final quenching.

With the casehardening operation today forming an almost necessary

part of our industry, it is necessary to offer practical information on the disadvantages of the process, if any, necessary, is

We are interested in the use of Laboratories in the development of the process, which has led to the development of special processes for casehardening.

These results are obtained at an extremely high temperature by heat treatment.

The process is based on the phenomenon that the nitriding gas penetrates the metal and forms a layer of nitrided metal on the surface of the parts, which is then hardened by heat treatment at a high temperature.

Previous to the use of the process, the steel was in a state of deterioration, and the use of the process has been found to be effective in preventing the deterioration of the steel.

Among the advantages of the process are the following:

(1) The process is simple and does not require any special equipment or apparatus.

(2) The process is rapid and does not require any special apparatus.

(3) The process is simple and does not require any special apparatus. The pieces, either in the form of bars or plates, are heated in an oven, which is, of course, at a high temperature, and the heat is then transferred to the metal, which is, of course, at a lower temperature than the oven.

(4) The process is simple and does not require any special apparatus. The depth of the heat treatment is determined by the absorption of the heat, which is, of course, at a high temperature. The growth of the heat treatment is determined by the depth of the heat treatment, which is, of course, at a high temperature. The heat treatment is entirely finished before the heat treatment is completed.

The use of the process is effective in preventing the deterioration of the steel.

part of our large engineering plants, the value of a process which would offer practically all the advantages of carbon casehardening without the disadvantages and expense incurred by the subsequent heat treatment necessary, is at once seen.

We are indebted to a German metallurgist, Dr. Fry of the Research Laboratories of Messrs. Fried. Krupp of Essen for an investigation which has led to the discovery of a new steel capable of being hardened by a special process which eliminates many of the disadvantages of carbon casehardening.

These results are possible because the hardening process is carried out at an extremely low temperature which eliminates the necessity of heat treatment for grain refinement and ultimate hardness.

The process of hardening is based, as in the case of carbonization, on the phenomenon of diffusion, but instead of carbon, nitrogen is allowed to penetrate the surface of the finished part to be hardened. This process of nitruation (as this hardening process is termed) consists briefly in heating parts made of this special steel, packed in a suitable container, to a temperature not exceeding 1025 degrees Fahr. in the presence of ammonia gas.

Previous work in this country and abroad has given ample evidence of deterioration of ordinary steels and non-ferrous alloys, due to the hardening effect of nitrogen at elevated temperatures but this development gives us a steel of such chemical composition that intercrystalline penetration, except to the depth required to produce a satisfactory case, is eliminated.

Among the advantages enjoyed by this development are:

(1) The outer portion of the steel is hardened in the actual treatment outlined above and no further heat treatment or ultimate quench is necessary.

(2) Clean surfaces are assured. There is but a slight gray, yellow or violet coloration formed and this is readily removed.

(3) The treated parts leave the furnace in a state of equilibrium, therefore no detrimental deformation, such as often occurs with quenched pieces, either under influence of time or temperature, can take place. It is, of course, understood that the material has been suitably treated to relieve original strains or those set up by heavy machining operations previous to this treatment.

(4) There is no warping of any kind as a result of this nitrifying process. Shapes remain perfectly intact, except that according to the depth of the hardened layer there is a slight increase in volume due to the absorption of nitrogen. In most cases this is negligible, but in cases of extremely high precision definite calculation can be made, as this slight growth is in direct ratio to the time involved in the operation and the depth of case required. Articles made of this material can therefore be entirely finished before treatment; even polishing is ordinarily done before the hardening process.

The maximum depth of penetration obtainable in commercial practice is approximately 1 millimeter.

While it is extremely difficult to determine the exact hardness resulting from nitration, tests conducted at the Krupp Works indicate that it is considerably harder on the surface than carbon-cased material. The highest degree of hardness penetrates to a depth of approximately two-tenths of 1 millimeter, from which point it gradually diminishes. The nitrurized portion is therefore firmly bound to the non-hardened portion due to this gradual diffusion.

The surface hardening effect extends to all surfaces of the steel exposed to the nitrogenous current, although it is possible to protect from such hardening effect any part desired.

An interesting and important consideration of this processed material is that it maintains its hardness when submitted to high temperatures whereas carbon-cased and quenched parts begin to lose hardness on any further reheating. The surface of a nitrurated article will not lose its hardness up to a temperature of 1025 degrees, Fahr.

At the conclusion of this paper, one of the most active discussions of the year followed.

H. A. Neeb, Jr.

SOUTHERN TIER GROUP

On Monday evening, January 17, the mid-winter meeting of the Southern Tier Group was held in the Arlington Hotel at Binghamton, New York.

Dinner was served to about fifty members and their guests. After the dinner, B. M. Stannard presided over the business session. Ways and means were discussed by which the membership of the Group might be increased. There has been a surprising interest shown in the few meetings held so far which has been very encouraging to those who have worked to establish the Group. After thanking those present for the interest they have shown and asking them to put forth increasing efforts to help the officers put the Southern Tier Group across as a live, wide-awake, growing member of the American Society for Steel Treating family, Mr. Stannard introduced as the speaker of the evening, J. C. Succop of the Heppenstall Knife and Forge Company, Pittsburgh, Pa.

Mr. Succop gave a talk on "The Making and Treating of Die Blocks." He had several films with him to help him in the telling of the story which gave the complete history of a die block from the selection of the raw material to the shipping of the finished block to the forge plant. Among other points which he stressed, Mr. Succop told with what care the blocks are heat treated by the maker to secure uniformity, explaining that due to this care it is advisable to purchase a heat-treated die block when possible rather than for the forge plant to attempt to do the heat treating.

The majority of those present were particularly interested in forging and an interesting discussion developed on why a die will give longer service on the second cutting than on the first, also on the cause and prevention of so-called grinding checks on shear blades.

The next meeting will be held in Elmira, New York, February 21, and will consist of a talk and general discussion of ordinary heat-treating problems.

G. D. Johnston.

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ST. LOUIS CHAPTER

The sixty-third monthly meeting of the St. Louis Chapter of the American Society for Steel Treating was held Friday evening, January 21, 1927, with about 35 members present. After the usual dinner, the meeting was called to order by our new vice-chairman, W. D. Thompson of Laclede Gas Light Company, on account of C. B. Swander, chairman, being detained at home on account of his wife's illness.

The speaker of the evening, Wm. Finkl of A. Finkl & Sons Company, Chicago, was introduced. He gave a practical talk on the manufacturing, forging and heat treating of die blocks, which was most interesting and educational. One of the points Mr. Finkl brought out was that many a block or piece of steel was broken in the heating before quenching and tempering. His chalk talk aroused an interesting discussion.

The meeting was both interesting and instructive, and there being no further business, Mr. Finkl was given a rising vote of thanks and the meeting was adjourned until February.

C. G. Werscheid.

SYRACUSE CHAPTER

On January 11, the members of the Syracuse Chapter were edified by a talk given by E. C. Bain, metallurgist of the Union Carbide and Carbon Research Laboratories, on "X-rays as Applied to Metallography".

X-rays are a form of radiant energy and the generalities we apply to other forms of radiant energy may be applied to X-rays. In the measurement of space lattices of metals, we apply the familiar principle of the diffraction of light by a grating. All metals are crystalline and the essence of crystallinity is arrangement of the atoms in an orderly fashion. If we make models of various orderly arrangements of atoms, we will observe that we can pass sets of parallel planes through the atoms and these planes may be considered as the diffraction grating for the diffraction of the X-rays. Knowing the wave-length of the X-rays, we can measure the diffraction angles and then compute the space between atoms. By placing a photographic film sensitive to X-rays in a calculated position we can produce a permanent record of the diffracted beams and from these records we can compute the space lattices of the metals.

The speaker showed slides illustrating the electric hook-ups for the production of X-rays and also photographs of the actual apparatus, and then diagrams of the space lattices of the various metals.

Having described his tool, Mr. Bain proceeded to show what tricks it could do. The diffraction diagram of pure copper; the diffraction diagram of pure gold; the diffraction diagram of a compressed mixture of fine powders of the pure metals; the diffraction diagram of a fused mass of the two metals; and, presto! the nature of solid solutions is made plain. Austenitic steels like high manganese and high nickel steels show a certain X-ray pattern; oil-hardening non-changeable steels as quenched show to some degree a similar pattern; ergo, the oil-hardening non-changeable steel as quenched contains austenite and we are thus able to more confidently account for certain changes that take place in these steels when they are

drawn. And so we can by means of the X-ray learn about alloy series certain facts which the microscope does not reveal and which make more understandable the physical behavior of these alloys.

The discussion aroused by this talk was very lively and the appreciation of the audience was well expressed by chairman Walter Bolton, in extending thanks to the speaker for his excellent talk and the practical manner in which he brought his subject to his listeners.

TRI-CITY CHAPTER

The meeting was held on Thursday evening, January 13, at the Davenport Commercial Club.

Forty-eight members of the local chapter and their friends braved the elements to attend the January dinner talk.

F. R. Palmer, metallurgist for the Carpenter Steel Company, of Reading, Pa., was the speaker of the evening. His talk was accompanied by slides and covered the field of tool design, cause of tool failure, preferred heat treatment, etc. Many new and interesting points were brought out concerning the practices just mentioned. It was indeed time well spent for all present.

Mr. Guthrie, Chicago district sales manager for the Carpenter Steel Company, was a guest of the evening.

The next January meeting of the local chapter, planned to take place at the International Harvester Tri-City Plant, has been postponed until the latter part of February.

G. A. Uhlmeyer.

WASHINGTON-BALTIMORE CHAPTER

Following a dinner at the Harrington Hotel, the Washington-Baltimore Chapter held its December meeting on the 17th in the Auditorium of the Commerce Building, 19th and Pennsylvania Ave., N. W., Washington, D. C.

A. L. Feild, research metallurgist of the Central Alloy Steel Corporation, Canton, Ohio, addressed the chapter on the subject "Open Hearth Practice."

The speaker started his talk, which was confined to the basic open hearth process, with a brief description of the open hearth furnace.

At the beginning of each heat, lumps of limestone are placed in the furnace and over them steel scrap is charged. When the charge is highly heated and flattened out by the flame, the molten iron, generally from a mixer, is added. The steel scrap gradually melts and the dissociation of the limestone proceeds. As the scrap melts it releases the lime from the bottom which joins the slag at the upper surface of the metal. The melting is carried out in an oxidizing atmosphere, containing water vapor and CO_2 as the active components. Free oxygen is not a factor of importance, the gases containing generally less than one per cent.

After the charge is melted down, the further conduct of the process is largely controlled by the behavior within the system metal-slag. Iron oxide is present in the slag and attacks the metal causing the carbon content to drop at a rate influenced by metal-slag and slag-atmosphere reactions. In order to hasten the oxidation of carbon, manganese and other elements, iron ore is added to the molten bath thus increasing the concentration of iron

oxide in the slag and this drop in the manganese content is so rapid that its heat is from 8

If the quality condition comb eliminated as quickly as it reaches the desired quiet in the ladle causing "effervescence" or "piping". The gases evolved examined under

When steel is more slowly as eliminated by the "pipe" or shriveling and heavy losses

The molten steel any other system liquid such as water equilibrium is maintained that there is a difference between two liquids.

A similar process of steel and slag to that recently determined of iron oxide (1) in the iron melt. This 0.94 per cent iron layer at the top it appears logical

iron layer. Here amount of FeO

Considering the molten layer to the molten steel are constantly molten steel itself contains the rate of diffusion spaces left open in the steel. Thus, if

oxide in the slag. The elimination of carbon then proceeds more rapidly and this drop in carbon content is accompanied by a drop in the proportion of manganese and phosphorus present in the metal. Silicon is oxidized so rapidly that its removal presents no problem. Usually the total time of the heat is from 8 to 14 hrs.

If the quality of the steel is not a primary consideration and good surface condition combined with low discard loss is important, the carbon is eliminated as quickly as possible and the metal tapped as soon as the carbon reaches the desired point. Such steel contains practically no silicon. It is quiet in the ladle, but large amounts of gases are evolved during solidification, causing "effervescence" or boiling action in the molds; no true shrinkage cavity or "pipe" is formed and the top surface of the ingot is almost level. The gases evolved consist mainly of CO and H₂. This "rimming" steel, when examined under the microscope, shows many oxide inclusions.

When steel of better quality is desired the process is caused to proceed more slowly as the desired carbon content is approached, the gases are eliminated by the use of silicon and the steel tends to form the well-known "pipe" or shrinkage cavity; this latter tendency may be largely overcome and heavy losses avoided by the use of hot-tops and big-end-up molds.

The molten "metal-slag" system may be considered in the same manner as any other system consisting of two immiscible liquids. For instance, if a liquid such as ammonia is added to the system water-chloroform, a certain equilibrium is established and ammonia is distributed in such a manner that there is a definite ratio between the amounts of ammonia dissolved in the two liquids.

A similar phenomenon should occur in the system consisting of molten steel and slag to which such a substance as iron oxide is added. It has been recently determined that if molten iron is covered by a slag consisting totally of iron oxide (100 per cent FeO) then 0.94 per cent of FeO would be found in the iron melt (at a temperature of approximately 1550 degrees Cent.). This 0.94 per cent of FeO is regarded as the saturation point for the molten iron layer at this temperature. When the slag contains 50 per cent of FeO it appears logical to expect 0.47 per cent of FeO $\left(\frac{0.94 \times 50}{100} \right)$ in the molten

iron layer. Hence, if *w* per cent of FeO is contained in the slag then the amount of FeO in the molten iron layer at the saturation point would be

$$0.0094 \, w \quad (I)$$

Considering the mechanism of diffusion of iron oxide from the slag layer to the molten steel it may be assumed that the molecules of iron oxide are constantly moving about in the slag and constantly bombarding the surface of the molten steel at the interface of molten steel and slag. If the molten steel itself contains some molecules of iron oxide, then it may be assumed that the rate of diffusion of iron oxide to the steel depends on the number of spaces left open between these molecules on the interface of slag and molten steel. Thus, if *w* and *Y* are the amounts of iron oxide in the slag and in

the molten steel respectively, then from equation (1) the rate of diffusion of iron oxide into molten steel may be given as follows:

$$\text{Rate} = K (0.0094 w - Y) \quad (2)$$

where K is a constant.

It follows from this fundamental equation that there is a maximum rate of diffusion when no iron oxide is present in the steel ($Y = 0$) and there is no diffusion at all when $Y = 0.94$.

It is an accepted fact that carbon is eliminated from the melt according to the reaction:



The rate of elimination of carbon may be expressed as $\frac{dX}{dt}$ where X is

the per cent of carbon in the metal and t the time.

Assuming 46 per cent of iron oxide in the slag which is at equilibrium with a steel containing 0.02 per cent of carbon, the following solution was offered. According to expression (1) the amount of iron oxide in the steel would be in this case

$$0.0094 \times 46 = 0.43$$

From the law of mass action

$$X \times Y = \text{constant} \quad (4)$$

where X and Y are the percentages of carbon and iron oxide respectively, in the steel at equilibrium.

$$\text{Hence } X \times Y = 0.43 \times 0.02 = 0.0086 \text{ (constant)}$$

$$\text{and } Y = \frac{0.0086}{X} \quad (5)$$

Bearing in mind equation (2) and also the fact that the rate of elimination of carbon is proportional to the rate of diffusion of iron oxide into steel, it is possible to write:

$$\frac{dX}{dt} = K (0.0094 w - Y) \quad (6)$$

and according to equation (5) the rate of elimination of carbon is:

$$\frac{dX}{dt} = K (0.0094 w - \frac{0.0086}{X}) \quad (7)$$

K is a furnace factor which depends upon the area of the furnace, on the contact between the gases and the bath, etc. As a matter of fact, the explanation of the elimination of carbon in some furnaces proceeding much faster than in others, is directly associated with this factor.

Equation

$$t = \frac{K' (2)}{1}$$

where X_1 and X_2 are the initial and final percentages of carbon in the metal.

From this it follows that the time required to reduce the carbon content of the metal from X_1 to X_2 is proportional to the square of the time required to reduce it from X_1 to X_0 at the same temperature.

It should be noted that the time required to reduce the carbon content of the metal from X_1 to X_2 is proportional to the square of the time required to reduce it from X_1 to X_0 at the same temperature.

The speaker has shown that the rate of diffusion of carbon in molten iron is much more rapid than in solid iron, and that in some cases it is rapid enough to spread freely in the system.

The speaker has shown that the processes in general use in the industry are far from being fully understood.

In the course of the discussion the following points were raised:

(a) Artificial slag formation.

(b) Globular slag formation.

(c) The effect of the slag on the rate of diffusion of carbon.

(d) The effect of the slag on the rate of diffusion of carbon.

(e) The effect of the slag on the rate of diffusion of carbon.

(f) The effect of the slag on the rate of diffusion of carbon.

(g) The effect of the slag on the rate of diffusion of carbon.

(h) The effect of the slag on the rate of diffusion of carbon.

(i) The effect of the slag on the rate of diffusion of carbon.

(j) The effect of the slag on the rate of diffusion of carbon.

(k) The effect of the slag on the rate of diffusion of carbon.

(l) The effect of the slag on the rate of diffusion of carbon.

(m) The effect of the slag on the rate of diffusion of carbon.

(n) The effect of the slag on the rate of diffusion of carbon.

Equation (7) when integrated shows that

$$t = \frac{K' (X_2 - X_1)}{K w^2} + \frac{K''}{K} \log. \frac{(1.08 w X_2 - 1)}{(1.08 w X_1 - 1)} \quad (8),$$

where X_2 and X_1 are high and low carbon contents respectively, at the beginning and end of the time interval t , and K , K' and K'' are constants.

From this equation diagrams were constructed showing a relation between carbon content and time for different amounts of iron oxide in the slag (48 per cent and lower) and different constants. The carbon content in the steel corresponding to a certain amount of FeO in the slag may, in the case of a normal boil, be predicted by means of these diagrams, once the constant of any furnace has been determined.

It should be borne in mind, however, that immediately after an ore addition the rate of carbon elimination is greater than is given by equation (8) and that in some local areas a certain acceleration of the process is to be expected.

The speaker pointed out that a similar equation when applied to manganese is much more complicated than in the case of carbon, for the latter is oxidized, spreads freely as a gas and is lost while the former after oxidation remains in the system and affects the equilibrium.

The speaker stated in concluding his talk, his belief that metallurgical processes in general and particularly such problems as were considered in this talk are far from being solved and that they need to be treated with a full knowledge of physical chemistry and mathematics.

In the course of the discussion it was suggested that:

(a) Artificial agitation of the melt may increase the rate of diffusion of iron oxide to the metal.

(b) Globules of silicates containing both iron and manganese may be formed during pouring and also during solidification.

It was explained also that:

(a) It is hardly probable that the depth of the bath affects the constant K .

(b) The amount of residual manganese is usually about 0.2 per cent but varies with the manganese content of the charge.

(c) The viscosity of the slag should be included in the rate equation and that thinning agents, such as fluorspar, sand and manganese oxide may have a pronounced effect upon the speed of reaction.

(d) The main supply of heat to the bath comes from an intimate contact of the flame with the melt and not from roof radiation. Radiation, however, makes the temperature more uniform. The velocity of the gases is also an important factor.

(e) Slag test samples are usually taken after additions of ore or of lime and the most representative sample is that one taken from the middle door where the melter is judging his operations. When several samples are taken simultaneously from different spots of the bath they should be thoroughly mixed in equal amounts.

(f) An addition of briquets containing calcium carbide recommended by

a German patent may be useful in the removal of residual oxides from the bath provided that they can be made to yield active carbide at the metal-slag interface.

(g) It is believed that an addition of MnO makes the slag more fluid but evidently it does not otherwise affect the rate of carbon elimination.

A. I. Kryniitsky.

The speaker at the January 7 meeting was J. A. Succop, chief of research, Heppenstall Forge and Knife Company, Pittsburgh, Pa.

Four reels of moving pictures on "The Manufacture of Heavy Forgings" and "The Story of The Die Block" were shown. There were panoramic views of the individual shops of the speaker's plant, as well as pictures of various operations, such as automatic charging of furnaces, tapping into ladles, pouring of molds, forging ingots and blanks by hydraulic presses and hammers, automatic handling of ingots and blanks during forging, chipping the blanks to remove surface defects, quenching, shear knives in operation, etc. This demonstration was accompanied by a detailed description and explanation.

A few points of the talk as well as of the discussion following it are given below:

Melting—Melting is carried on exclusively in open hearth furnaces. The principal reason for this rather than electric melting equipment, is the large size of ingots and therefore the large furnace capacity required. To be assured of good quality steel acid furnaces only are used, this process demanding careful operation and well selected scrap. The charge is composed of high grade pig iron (often of Swedish origin) to which is added some basic steel scrap and plant scrap (acid).

Ingots—Only bottom-poured, hot-top ingots are produced; they are usually corrugated. The surface of the molten metal after pouring is covered with ashes to keep the top hot as long as possible. Ingots are stripped at about 1400 degrees Fahr. and are transferred as quickly as possible to pits in which they are cooled slowly.

Forging—Ingots are heated to a suitable temperature and forged by hydraulic presses or hammers. More compact steel and better transverse test results are obtained when heavy cross sectional reductions are practiced (within limits) and consequently ingots as large as 44 inches in mean diameter are used. To insure ample working even at the center of heavy sections, all forgings over 6 inches are worked by hydraulic presses. For sections under 6 inches hammers are preferred, for they are more rapid and less costly to operate and produce a somewhat better surface. Much care is taken to remove all surface defects from billets before final forging.

Heat Treatment—Forged blanks are always normalized prior to quenching and tempering. In the case of the largest and most complex forgings, only air quenching is employed, in order that cracking may be minimized. The scleroscope hardness of the working face of shear knives is generally 95 while the hard face of forging dies varies according to the die size with a minimum of about 45 for the larger ones; the core and shank should be soft, usually

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about 35. A great problem is the avoidance of warpage and the straightening of warped parts, both knives and finished dies. This is particularly serious in shear knives made of high speed steel.

Inspection—A very rigid inspection is practiced, the whole surface of finished parts being inspected for hardness and imperfections. About $\frac{3}{8}$ -inch of the working face of die blocks is ground off to remove the decarburized layer and surface defects. Dies are inspected also by dropping a heavy weight on their hard surface and by suspending them in the air and listening to the sound produced by the blow of a hammer.

Composition of Steel Used—A carbon vanadium steel is used for shear knives. There is some use also of high speed steel for this purpose. This practice the speaker believed would extend rapidly. Die blocks are made of steel having a chrome-nickel base (Ni = about 1.5 per cent and Cr = about 0.80 per cent to which tungsten, vanadium, molybdenum or other elements are sometimes added. Titanium and zirconium have been tested as scavengers but there is some difference of opinion in regard to their value in die-block steels.

Insert Dies—It was mentioned that in some cases insert dies, usually from 2 to 3 inches larger than the impression itself, are used to reduce the cost of making dies, as well as that of correcting warpage and that resulting from breakage; this practice is most economical in producing very large numbers of the same forging.

A. I. Krynetsky.

WORCESTER CHAPTER

The January meeting of the Worcester Chapter was held at the Baratti & Ble Restaurant at Worcester, Massachusetts, on Thursday, January 6, 1927. Dinner was served at 6:00 p. m. to about fifty members and guests.

Following the dinner the speaker of the evening, Prof. Albert Sauveur of the Harvard Engineering School, author of "The Metallography and Heat Treatment of Iron and Steel", and a contributor of many valuable papers dealing with the study of iron and steel metallurgy, was introduced by the chairman and delivered a talk on "Eutectoid Steel".

Prof. Sauveur considered in his talk the origin of the word *eutectoid*. This word was derived from the word *eutectic* and had a great many peculiar sounding names until finally the word *eutectoid* was universally adopted to describe this particular structure of steel. Prof. Sauveur then showed the pictures of a great many men who are responsible for much of our knowledge of iron and steel. It was probably the first time that most of us had ever seen their faces. The professor then named several structures obtained in steel, showing how some of these men have been honored by having their name used in relation to the structure so named.

If all the different steels in the world except one kind were to be destroyed, and we had to choose or select which steel we would like to have remain, our selection, said Prof. Sauveur, would be eutectoid steel, as this particular steel by virtue of its flexibility can be adapted to nearly every purpose. It may be made extremely hard by heat treatment so as to be used

on any kind of tool work. By alloying with other elements, this particular steel can vary from a water-hardening to a self-hardening steel. It is not used for parts requiring maximum ductility although it may obtain great softness and ductility by spheroidizing or similar treatment. The structure retained by spheroidizing has properties characteristic of a good bearing metal. The hard particle imbedded in the soft ferrite.

In alloying eutectoid steel a great number of different properties can be obtained. With the addition of nickel the critical point is lowered considerably and the eutectoid point is moved to a lower carbon content. The effect of nickel in lowering the critical temperature was explained by Prof. Sauveur as pearlite containing less carbon, the saturation becoming less at lower temperatures. The pearlite of nickel steel is not the same as the pearlite of carbon steel, being finer and appearing more like a sorbitic structure.

Finally a discussion in answer to several questions ended the talk.

After an expression of thanks to the speaker, the meeting was closed by the chairman.

C. G. Johnson.

Members of the American Society for Steel Treating, and especially those of the Worcester Chapter, regret the loss of one of their colleagues,—Victor Carlstrom, who was at the time of his death, superintendent of the Worcester Stamped Metal Company. Mr. Carlstrom was killed in an automobile accident in December last.

THE DECOMPOSITION OF THE AUSTENITIC STRUCTURE IN STEEL (Continued from Page 232)

While the maximum temperature difference between the outside and the inside must be greater in quenching from the higher temperature, and the resulting stress greater, it is believed that the greater stability of the more concentrated austenite and the larger grain is the more important factor and results in the larger amount of austenite. Also, a given amount of stress may be expected to produce fewer slip lines in a coarse structure than in a fine-grained structure.

SOLIDIFICATION OF STEEL IN THE INGOT MOLD

(Continued from Page 276)

probably larger, maybe around .04. The effective coefficient depends on the degree to which the shell shrinks inwardly while the steel is still freezing, thereby pushing up the steel and preventing the pipe from going as far as it otherwise would.

G. A. DORNIN: There are two points which I think are particularly valuable in this paper. One is that it gives a law that can be followed as closely as practical. These formulae cannot be exactly applied but can always be used in that direction. The other is the extreme importance brought out of pouring steel as cold as possible.

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Items of Interest

DR. F. C. LANGENBERG, director of laboratories at the Watertown Arsenal, Watertown, N. Y., has become associated with the Climax Molybdenum Company, New York, as head of its research department. Dr. Langenberg is a member of the American Society for Steel Treating and was awarded the Henry Marion Howe medal at Chicago for the year 1926.

N. H. Boynton has recently been made assistant sales manager of the National Lamp Works at Cleveland of the General Electric Company, Schenectady, N. Y.

D. G. Clark was elected a director of the Firth-Sterling Steel Company at a recent meeting. Mr. Clark has been affiliated with the company since 1903. Upon his return from France in 1919, he took charge of the company's business in the east, with headquarters in New York City. His work in connection with the heat treatment of high speed steel is well known in the west and his recent activity in the introduction of stainless steel in the east has been recognized by the Iron and Steel Institute.

M. E. Greenhow is now affiliated with the Nordberg Manufacturing Company in the capacity of metallurgical engineer. This became effective February 1, 1927.

Arthur B. Domonoske, member of American Society for Steel Treating, is now professor of mechanical engineering at Stanford University. He was formerly professor of experimental engineering in the shops of the University of California.

T. L. Joseph, a member of North-West Chapter, of The American Society for Steel Treating, and superintendent of the North Central Station of the U. S. Bureau of Mines, recently received the J. E. Johnson, Jr., award. The award was made by the board of directors of the American Institute of Mining and Metallurgical Engineers and is the income from a fund donated by Margaret Hilles Johnson in memory of her husband.

C. E. McGregor, formerly of the Republic Flow Meters Company, has joined The Brown Instrument Company, Philadelphia, Pa., for which concern he will handle the Brown Electric Flow Meter, in the Chicago territory.

Mr. McGregor received his technical education at the Sheffield Scientific School of Yale University, graduating in 1910. During the past ten years he has been connected actively with flow meter development and sales.

D. A. Stuart & Company, 2753 South Troy Street, Chicago, have for distribution a new semi-technical booklet on the subject of broaching oil. Sent on request gratis.

That the United States during the present year will take final legislative action to place its merchandising on the decimal metric basis in weights and measures was the declaration made at the annual executive conference of the All-America Standards Council, held in San Francisco, January 6th.

"Metric legislation is now prominent before both houses of Congress," stated Aubrey Drury, director of the Council, "and when a vote is called, victory appears assured for the metric standards, which are on the convenient decimal ratio, like our dollars-and-cents currency. A recent canvass of the United States Senate has indicated an almost certain majority for metric adoption.

"Obstructionists have always fought bitterly to kill in committee any metric action. The great basic strength of this issue in Congress was shown the one and only time it was allowed to come up for a general vote. In the House of Representatives, the Stone Metric Bill successfully passed two of the necessary three readings, but after a dispute on rules of order it was recommitted to the Committee on Coinage, Weights and Measures on request of its author, with expectation of a later vote, indefinitely delayed. The metric legislation was never defeated in a general vote in Congress. It can and will win in the 1927 vote.

"The metric issue has won overwhelming victories in more than 40 of the great parliaments of the world. At one time a metric standards bill passed the House of Lords in Britain; at another, lacked only 5 votes to win in the House of Commons. The House of Representatives in Australia has endorsed the decimal weights and measures by a vote of 36 to 2. All civilized nations except the United States and the British Commonwealths are now on the metric basis in merchandising, and British units are largely different from ours."

Declaring that decimal metric weights and measures for the United States have been endorsed by 7 Congressional committees, but with never a general vote in Congress, metric advocates throughout the country are urging a "show-down" in 1927 and predict a definite victory at the roll-call.

The Brown Instrument Company offers new Flow Meter Catalogs. In a new catalog, recently issued by The Brown Instrument Company, the operation and advantages of the inductance bridge principle in this application is fully described and illustrated. The catalog opens with a concise introduction outlining the fundamentals of flow meter design, principle uses of flow meters, and benefits gained from such use. The various elements of the complete Brown Electric Flow Meter line are pictured and described. Features so presented include the Brown thin-plate orifice, contactless electric manometer, double-range manometer, low-pressure manometer, weir-type manometer, flow indicator, electrically operated circular-chart flow recorder, 5 figure dial integrator, double scale indicator, recorder-integrator, indicator-recorder integrator, "automatic planimeter" recording total flow, 2-pen and 3-pen recorders, styles of cases, strip-chart recorders, Brown boiler recorder, Brown automatic controlling and signalling flow meters, Brown electric liquid level recorder, Brown electric steam boiler water level gage, and the general line of

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